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CRATER REPAIR OF NORTH AUXILIARY AIRFIELD, SOUTH CAROLINA

by

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This study was conducted to evaluate two rapid runway repair techniques. Two craters, designated west and east, were blown in an east-west runway located at North Auxiliary Airfield, South Carolina. The west crater was repaired using US Air Force Europe's precast slab technique. The slabs used for the repair were imported from Germany and placed over a ballast rock-leveling course base. The east crater was repaired with a fiberglass

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20. ABSTRACT (Continued).

CONT foreign object damage (FOD) cover placed over a crushed stone base (ballast rock choked with a graded stone). Repairs were made by a Prime BEEF Team from Charleston Air Force Base under the supervision of Air Force Engineering Services Center personnel.

After the craters were repaired, traffic was applied to the repairs with an F-4 aircraft and a specially designed single-wheel test cart which simulated F-4 and F-15 aircraft traffic. The sequence of test traffic applied to the crater repairs was as follows: (a) proof-testing the repairs with the F-4 test cart, (b) F-4 aircraft operations, (c) F-15 test cart traffic, and (d) F-4 test cart traffic. The findings from the traffic testing of the crater repairs ~~showed the following for each crater repair~~ are given.

West crater (precast slab repair) findings were:

a. Early F-4 traffic (proof-testing and aircraft) and the F-15 traffic generated crack and/or breaks in the slabs, but these cracks and/or breaks did not impair the performance of the crater repair.

b. Both the F-4 and F-15 load cart traffic produced spalling that would likely have been a FOD problem.

c. The initial movement (tipping) of the slabs indicates that a better seating method or some degree of compaction might be desirable before subjecting a repair of this design to aircraft traffic. The proof-testing reduced the movement or tipping by one-half or more, indicating a need for compaction.

d. The traffic by the F-4 load cart also indicated that some type of compaction might be desirable.

e. The F-4 aircraft bounced and had a side-to-side rocking motion at the 20- to 30-knot taxi speeds; however, the pilot did not consider this a major problem. Roughness problems were not encountered at speeds slower or faster than 20 to 30 knots.

East Crater (FOD cover repair) findings were:

a. The crater repair as built was underdesigned.

b. The thickness of the crater fill materials (base course and ballast) were inadequate to withstand the test traffic.

c. Although the test results indicate poor performance of this type of crater repair, the performance would have been considerably improved if the base material had been constructed at optimum moisture content.

d. The poor performance of the FOD cover under traffic was mainly attributed to hinge problems (tearing and spalling) and could be solved by either eliminating or reinforcing the hinges.

PREFACE

This investigation was conducted by the Geotechnical Laboratory (GL), US Army Engineer Waterways Experiment Station (WES), during the period April 1983 to September 1984. The study was sponsored by the US Air Force Engineering and Services Center (AFESC), Tyndall Air Force Base, Florida, under Military Interdepartmental Purchase Requests N-83-6 and N-84-26 entitled "Aircraft Testing of ALRS." AFESC project officers for this study were Captains Henry F. Kelly, J. D. Wilson, and David F. Ruschmann.

This study was conducted under the general supervision of Dr. W. F. Marcuson III, Chief, GL; Dr. T. D. White, former Chief, Pavement Systems Division (PSD), GL; Mr. H. H. Ulery, Jr., Chief, PSD; Mr. J. W. Hall, Jr., Chief, Engineering Investigations Testing and Validation Group, PSD; and Mr. R. W. Grau, Chief, Prototype Testing and Validation Unit, PSD. Personnel of the Pavement Systems Division who took part in the study were Mr. S. J. Alford, Ms. M. D. Alexander, and Messrs. A. J. Bush III and C. W. Dorman. This report was prepared by Messrs. Alford and Bush.

Commanders and Directors of the WES during this investigation and preparation of this report were COL Tilford C. Creel, CE, and COL Robert C. Lee, CE. COL Allen F. Grum, USA, was Director of WES during publication. Technical Directors were Mr. Fred R. Brown and Dr. Robert W. Whalin.

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CONVERSION FACTORS, NON-SI TO SI (METRIC) UNITS OF MEASUREMENT

Non-SI units of measurement used in this report may be converted to SI (metric) units as follows:

Multiply	By	To Obtain
feet	0.3048	metres
inches	2.54	centimetres
kips (force)	4.448222	kilonewtons
knots (international)	0.5144444	metres per second
miles (US statute)	1.609347	kilometres
pounds (force) per square inch	6894.757	pascals
pounds (mass)	0.4535924	kilograms
pounds (mass) per cubic foot	16.01846	kilograms per cubic metre
pounds (mass) per cubic inch	27.6799	grams per cubic centimetre
square feet	0.09290304	square metres
tons (2,000 pounds, mass)	907.1847	kilograms

CRATER REPAIR OF NORTH AUXILIARY AIRFIELD, SOUTH CAROLINA

PART I: INTRODUCTION

Background

1. This report describes an evaluation of the rapid runway repair techniques conducted by US Air Force personnel at North Auxiliary Airfield (NAA) during the period July-September 1983. NAA is located approximately 4 miles* south of the town of North, South Carolina. Two craters, designated west and east, were blown in the east-west runway, and then different techniques were demonstrated for the repair of the two craters. The center line of the craters was 18.75 ft north of the runway center line. The east-west runway was constructed in the early 1949's and consists of 6 in. of portland cement concrete (PCC) placed over the existing silty-sand subgrade. The west crater was repaired using US Air Force Europe's (USAFE) precast slab technique. The slabs used for the repair were imported from Germany. The east crater was repaired with a fiberglass foreign object damage (FOD) cover placed over a crushed stone base (ballast rock choked with graded stone). Both craters were repaired by a Prime BEEF Team from Charleston Air Force Base (AFB) under the supervision of Air Force Engineering Services Center (AFESC) personnel. A representative from USAFE was present for consultation during the precast slab repair of the west crater. All repairs were made using a combination of Air Force and rental equipment. The US Army Engineer Waterways Experiment Station (WES) was responsible for (a) in-place field tests (moisture content, density determinations, California bearing ratio (CBR), and plate-bearing tests) required to characterize the materials used to backfill the craters; (b) recording data before, during, and after traffic required for evaluating the two crater repair techniques; and (c) providing a report giving results of construction and performance of the crater repairs during traffic.

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* A table of factors for converting non-SI units of measurement to SI (metric) units is presented on page 3.

Objective and Scope

2. The overall objective of this investigation was to validate Air Force designs/concepts for crater repairs with F-4 aircraft traffic and with simulated F-4 and F-15 aircraft traffic. This objective was accomplished by:

a. Simulating two craters in an existing airfield pavement and then repairing the craters and testing the performance of these repairs by operating two F-4 aircraft and aircraft load carts on the repaired areas.

b. Performing in-place field tests to characterize the various materials used to repair the craters.

c. Performing rod-and-level readings and straightedge measurements before, during, and after test traffic as required to determine the performance of the crater repairs.

d. Preparing a report giving results of construction and the performance of the crater repairs during traffic. This report gives a description of each repair technique, the construction procedure used for each repair, and performance of the PCC slabs and FOD cover during aircraft and load-cart (simulated) traffic.

e. Providing photographic and video documentation of the construction and traffic testing.

PART II: CRATER REPAIRS

Design

3. The crater repairs selected for construction and testing during this investigation were based on the results of previous Air Force studies. One of the repairs (west crater) consisted of placing precast slabs over the existing subgrade, and the second repair technique (east crater) consisted of placing an FOD cover over a crushed stone base material. Each of these repairs was designed to withstand 150 coverages of an F-4 aircraft with only minor maintenance required during traffic.

Construction of Crater Repairs

Precast slab repair (west crater)

4. The west crater was formed in the existing 6-in.-thick PCC by exploding a charge (TNT, ammonium nitrate, and fuel oil) placed 5.7 ft beneath the PCC. Figures 1 and 2 show plots of the runway surface before and after the crater was formed. The depth at which the charge was placed is also shown in Figure 1. The cross sections shown in Figure 1 were taken in the north-south direction, which is transverse to the runway center line and perpendicular to the direction of traffic. The measurements plotted in Figure 2 were taken parallel to the direction of traffic. The plots in these figures show the crater to be approximately 15 to 15.5 ft in diameter and 3.25 ft deep. The fallback or loose subgrade material in the bottom of the crater extended to a depth of 4.5 feet. Density tests were run on the fallback or silty sand material (Figure 3, curve 3), and the results are shown in Table 1. At the lip of the crater the debris and upheaval of the PCC pavement ranged from approximately 0.8 to 1.6 ft above the original grade of the runway. Photo 1 shows the debris and the inside face of the crater.

5. After the crater was formed and surveyed, it was determined that an area 26.35 by 33 ft was needed for placement of the precast slabs (4 slabs wide and 5 slabs long). This area would allow removal of the upheaval in the pavement surrounding the crater and allow for "squaring" of the crater to accommodate the square precast slabs which were 78.5 in. on each side and 6 in. thick. The debris, with the exception of that located at the lip of the

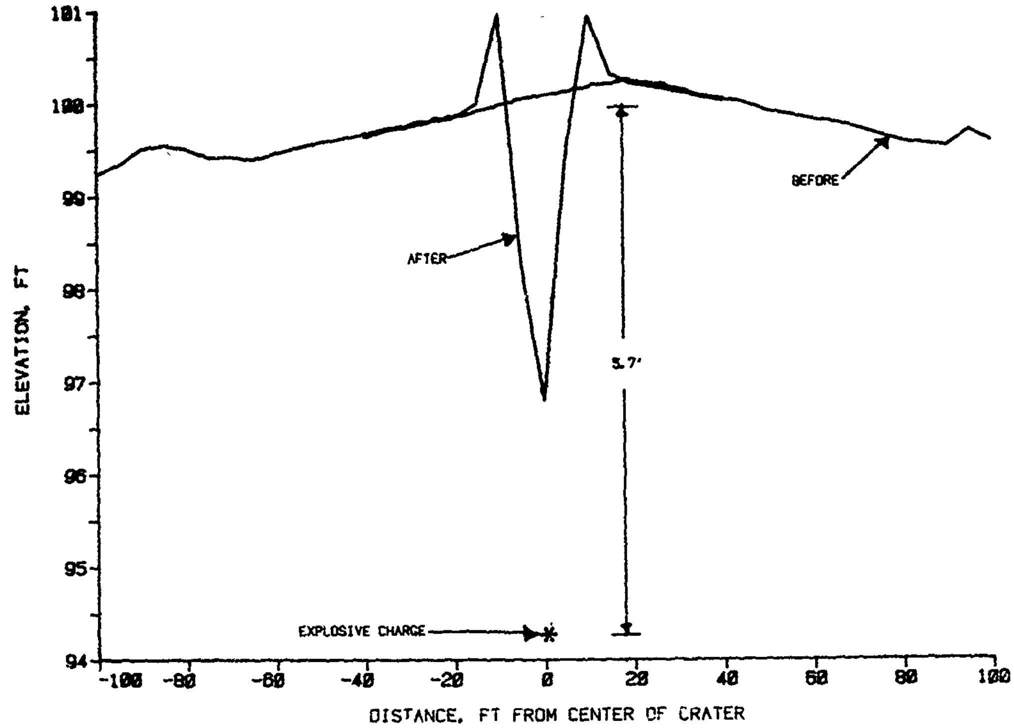


Figure 1. Runway surface cross section before and after the west crater was exploded in a north-south direction (across runway), also depth at which charge was placed, precast slab repair

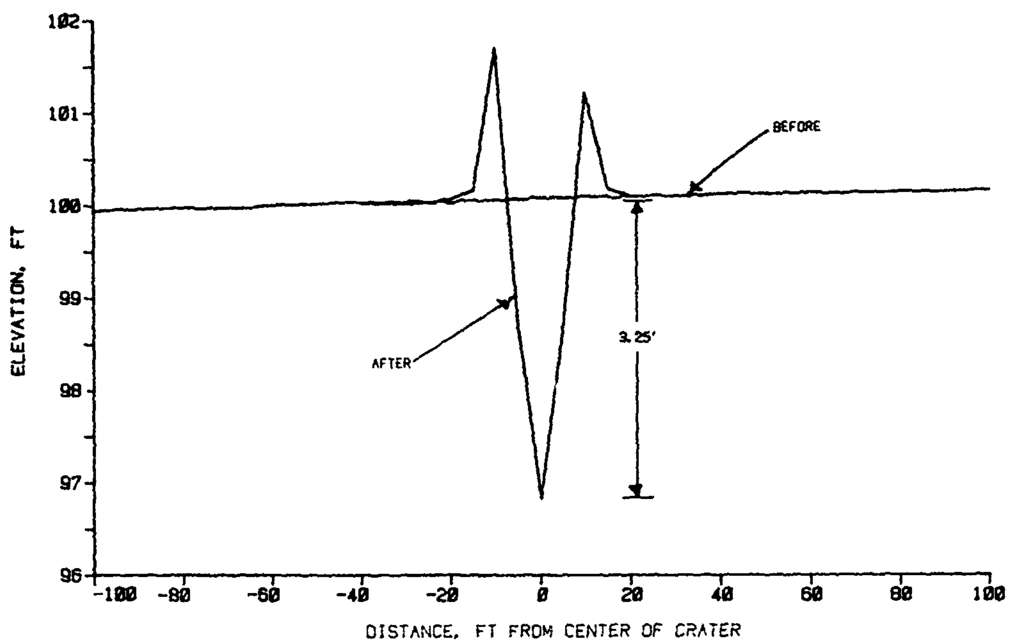
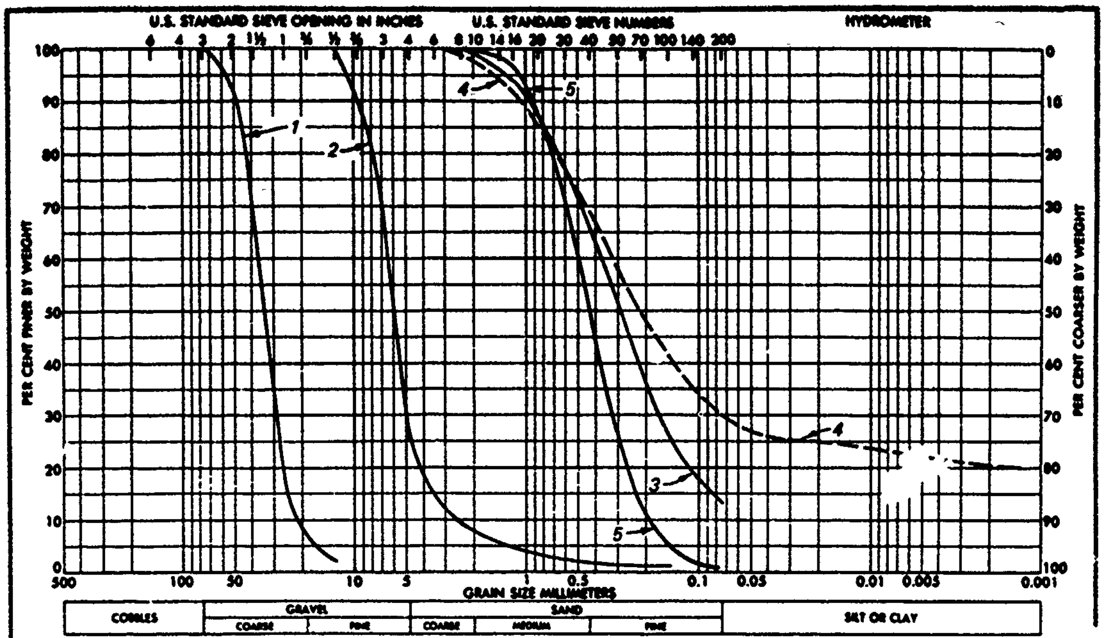


Figure 2. Runway surface before and after the west crater was exploded in a west-east direction (direction of traffic), precast slab repair



SAMPLE NO	ELEV OR DEPTH	CLASSIFICATION	NAT W%	LL	PL	PI	PROJECT
1		CRUSHED GRANITE (BALLAST)					
2		CRUSHED GRANITE (NO. 789)					
3		SILITY SAND (SP-SM)					AREA
4		CLAYEY SAND (SC) RED		27	11	16	
5		SAND (SP) (MASON)					BORING NO
		GRADATION CURVES					DATE

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Figure 3. Gradation of materials in precast slab repair

crater, was piled with a motor grader (Huber, Model 10D, Photo 2) and then loaded onto dump trucks and hauled to a stockpile. The trucks used for hauling were an International, Model S1700 with a 2.5-ton metal dump bed; and a Chevrolet, Model C60 with a 5-ton flat bed with wooden sides. A Clark-Michigan, Model 35C, front-end loader with a four-way bucket was used to load the debris. The front-end loader shown in Photo 3 was used to remove the large pieces of PCC. An area approximately 26.35 by 33 ft with the crater at the center was cleared of debris. The 33-ft sides were parallel to the direction of traffic. The 6-in.-thick PCC along the sides were sawed with a Christensen Concrete Saw, Model CK40 (1983) (Photo 4) to "square" up the crater. The PCC between the saw cut and the crater was originally to be broken up with a truck-mounted pavement breaker, an Arrow Hammer, Model HG-1250; however, due to a breakdown of this equipment early in the work, the removal was performed using a Case backhoe, Model 58D, and the front-end loader equipped with the four-way bucket (Photo 5). These two pieces of equipment were used to remove the PCC between the saw cut and the crater and the larger particles of PCC ejecta that had fallen into the crater after the

blast. After the removal of the large PCC particles, a portion of the loose fallback material (silty sand) was removed from the center of the crater with the backhoe. This was required so that a minimum thickness (24 in.) of ballast rock could be placed in the center of the crater. Cross sections of the crater after excavation of the silty-sand material are shown in Figures 4 and 5.

6. After all the debris and a portion of the silty-sand material was removed from the crater area, density and moisture content determinations were performed on the subgrade material located between the crater and the saw cut. The results of these tests are shown in Table 1. On the west side of the crater between the crater and the saw cut, streaks of a clayey sand were intermixed with the silty sand subgrade; Figure 3, curve 4 shows the gradation of this material. These streaks ranged in depth from 2 to 6 in. deep.

7. An open-graded crushed granite (ballast) (Figure 3, curve 1) was placed in the crater over the loose fallback material. The depth of the ballast ranged from 22 to 29 in. (Figures 4 and 5). This material was dumped into the crater from the dump trucks and spread by the front-end loader with the final leveling being accomplished with hand tools, rakes, and shovels. The ballast, which served as a subbase, was placed so as to leave a 9-in.-deep hole over the entire dimension of the crater area. Photo 6 shows the crater repair after placement of the ballast. After ballast placement, a leveling course of crushed granite was placed over the entire area. The leveling course material was also an open-graded granite but of a smaller size (Figure 3, curve 2). This material was dumped into the crater from the dump trucks and spread initially with the front-end loader. Photo 7 shows the crater with a portion of the leveling course in place and it also shows an area in the PCC outside the crater repair that required patching with Silikal; the PCC in this area was cracked due to the upheaval but was not recognized as such in the repair layout. Therefore, the cracked PCC outside of the saw cut was removed and patched. After placement of the leveling course, a screed pipe (Photo 8) was set inside the crater repair such that specially designed screeded boards could be used to screed the leveling course. Screeding was accomplished using the pipe and the edge of the crater as guides (Photo 8). The leveling course was screeded to an elevation which would result in the surface of the precast slabs being 0.5 in. higher than surrounding pavement. The screed boards were pulled by hand and the leveling course was adjusted in

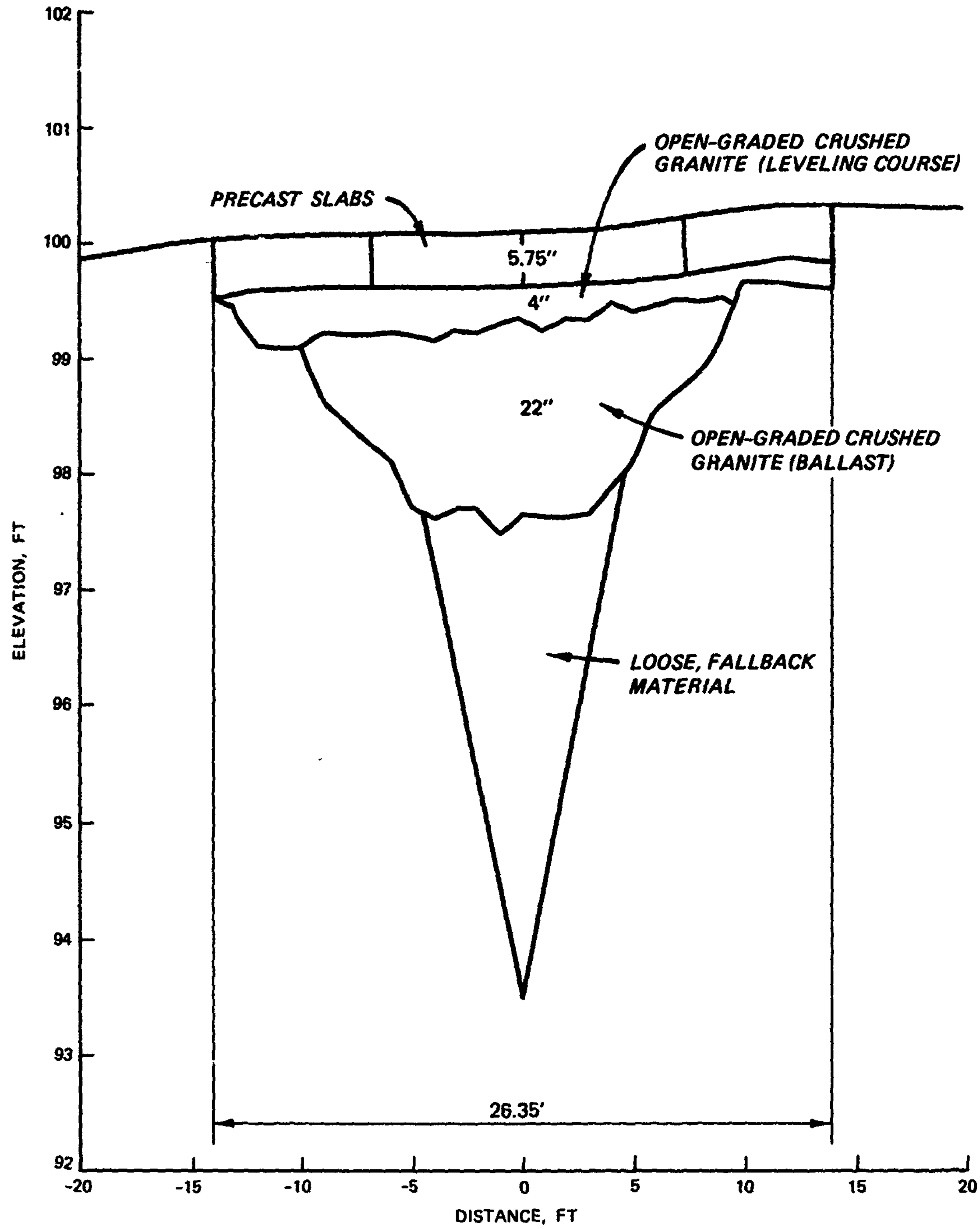


Figure 4. Thickness of materials used in the precasst slab repair, north-south direction

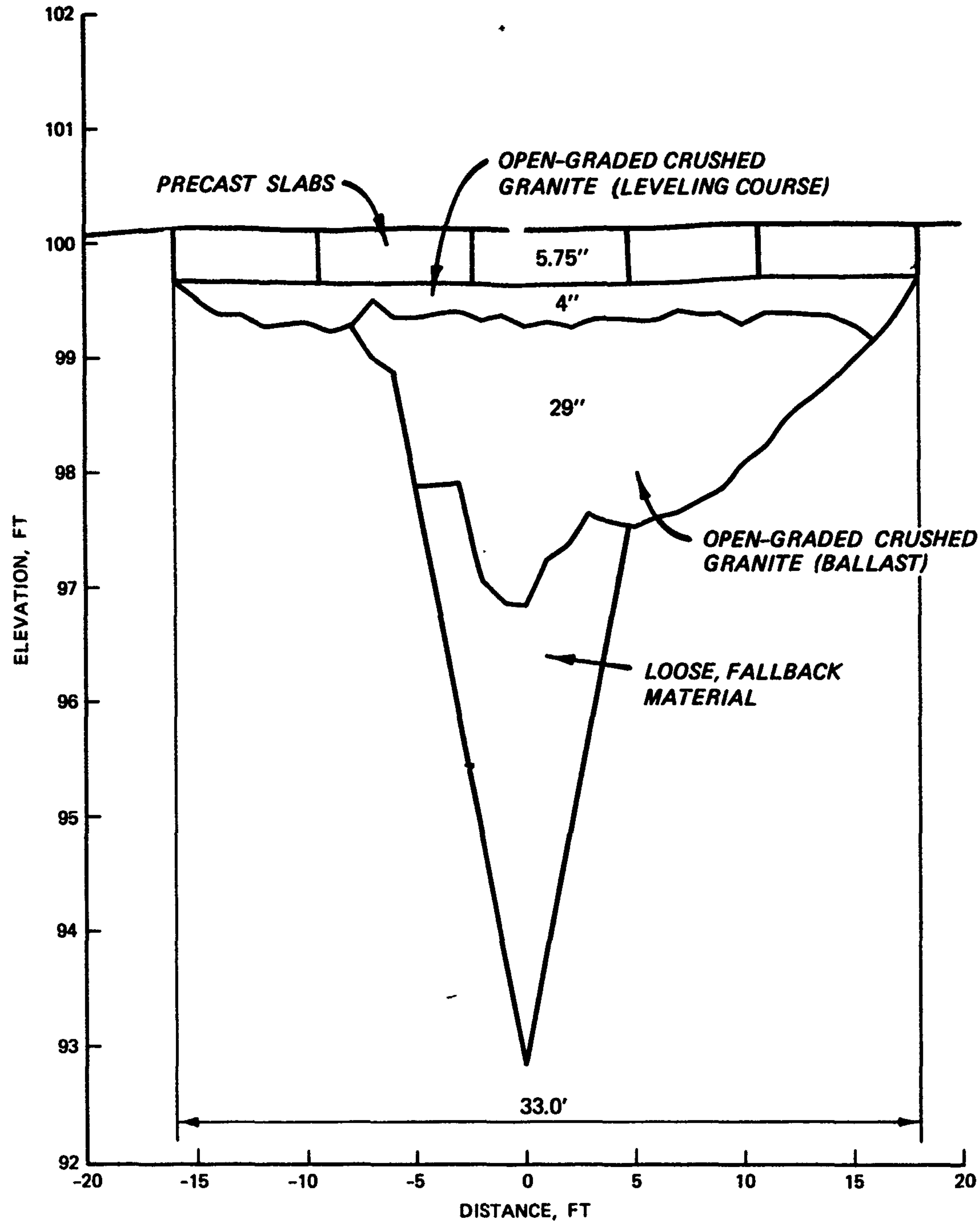


Figure 5. Thickness of materials used in the precast slab repair, west-east direction

front of the screeds using shovels and rakes (Photo 9). After the area was leveled, the precast slabs were taken off a lowboy trailer and placed in the crater with front-end loader. The front-end loader was equipped with lift extensions attached to the bucket, a chain hoist across the extensions, and lifting keys attached to the chain hoist. The lifting keys were inserted into two lifting keyholes cast at third points along the slab center line. The slabs were lifted and carried to the crater where spacers made of 0.25-in.-thick steel had been placed on two sides of the crater (edge). The spacers were used in placement of all the slabs to maintain a uniform 0.25-in. spacing between the slabs and between the slabs and the edge of the crater. Photo 10 shows the first slab being placed in the southeast corner of the crater repair. As can be seen in Photo 10, hand guidance was required during slab placements as the front-end loader lowered the slab. After the first row of slabs (5 slabs) had been placed, the screed pipe was again set up inside the crater repair and leveling for the second row of slabs was accomplished using the pipe and the edge of the first row of slabs (Photo 11). After the second row of slabs were placed, the above process was repeated for the third row. Leveling for the final (fourth) row of slabs was accomplished by using the screed boards on the edge of the third row of slabs and on the outside edge of the crater (Photo 12). Figures 4 and 5 show the thickness of the leveling course under the slabs. After all the slabs were in place, a loaded dump truck was driven over the slabs to seat them. This lowered the slabs the approximate 0.5 in. that the leveling course had been overbuilt and left the slabs almost flush with the surrounding PCC.

8. After seating the slabs, a slab was removed from the second row to allow the modulus of subgrade reaction, k , and density tests to be performed on the leveling course. Results from these tests are shown in Table 1.

9. When the testing was completed on the leveling course and the slab was replaced, mason sand (Figure 3, curve 5) was used to fill the spaces (0.25 in.) between adjacent slabs and between the slabs and the crater edges. The sand was "washed" into the joint spaces (Photo 13) using water from a fire truck. During this process it was noticed that the spaces between several of the slabs and the existing pavement were greater than 1 in. These spaces were filled with the crushed granite used for the leveling course (Photo 14).

<u>FOD cover repair (east crater)</u>

10. The east crater was formed in the existing 6-in.-thick PCC pavement

in the same manner as the west crater. Figures 6 and 7 show the cross section of the runway surface before and after the crater was explosively formed. These figures show the crater depth to range from 4.4 to 4.6 ft deep and the width to range from 14 to 16 ft wide. The upheaval of the pavement and the debris at the lip of the crater ranged from 0.75 to 1.1 ft above the original grade of the PCC runway. Photo 15 shows the inside face of the crater and part of the debris surrounding the crater. The depth of the fallback or loose material in the bottom of the crater was not measured but it appeared to be approximately the same as that of the west crater, 4.5 ft. Density tests were performed on this material (silty sand, Figure 8, curve 3) and the results are shown in Table 2. As can be determined by comparing curve 3 in Figure 3 and curve 3 in Figure 8, the silty-sand material in the west crater was essentially the same as that in the east crater.

11. The debris from around the crater was cleaned up using the motor grader and front-end loader, the same as for the west crater. The backhoe and front-end loader were used to remove the PCC pavement that was broken up outside the crater by the blast forming the crater. After the broken PCC material was removed, the area (crater) to be repaired was approximately 25 ft in diameter. Removing this broken-up PCC also left the subgrade (silty sand) extending out approximately 4.5 ft around the original crater. A backhoe was then used to push this subgrade material mixed with a small amount of ejecta into the original crater (Photo 16). Cross-section plots presented in Figures 9 and 10 show the amount of backfill (ejecta and silty sand) used in filling the original crater. After the original crater was filled, the subgrade material inside the 25-ft repair area was compacted with a Case tracked front-end loader, Model 45D (Photo 17). Density tests were run on the subgrade of the crater repair and the average values of three values are shown in Table 2. After testing the subgrade, an open-graded crushed granite (ballast, same as the subbase used in the slab repair) (Figure 8, curve 1) was placed in the crater. The ballast was dumped into the crater from dump trucks and spread initially with the backhoe (Photo 18) with final leveling accomplished by hand using shovels and rakes. Photo 19 shows the crater repair with the ballast in place. Cross-section plots shown in Figures 9 and 10 indicate the thickness of the ballast. A base course consisting of a well-graded crushed granite (Figure 8, curve 2) was placed over the ballast. The crushed granite was dumped into the crater repair from dump trucks, spread by the backhoe, and

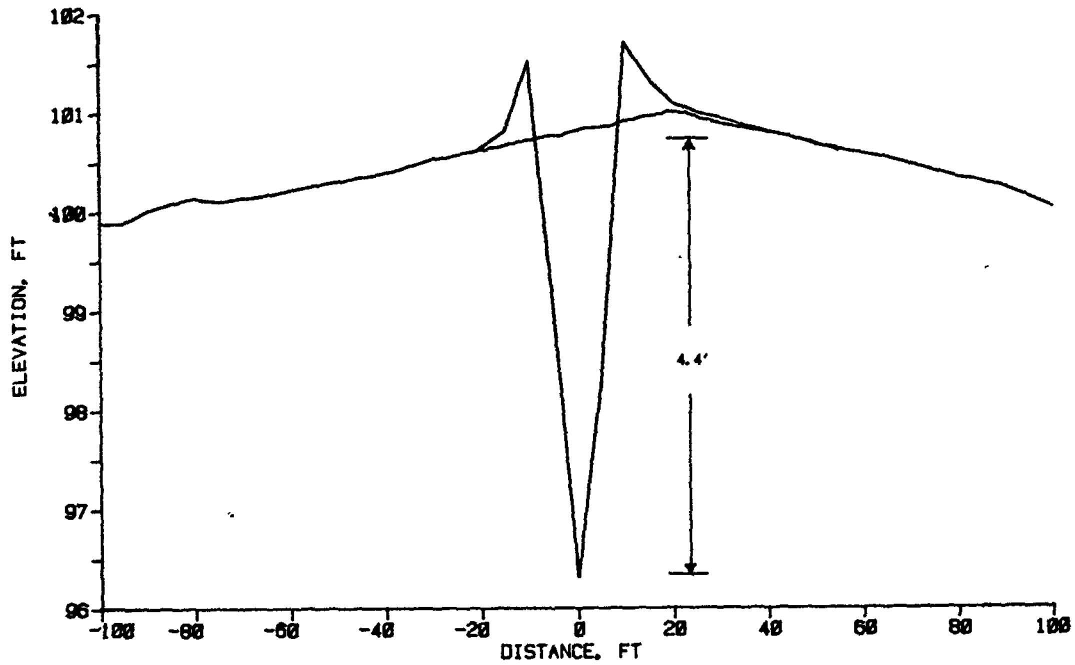


Figure 6. Runway surface before and after crater was exploded in a north-south direction, FOD cover repair

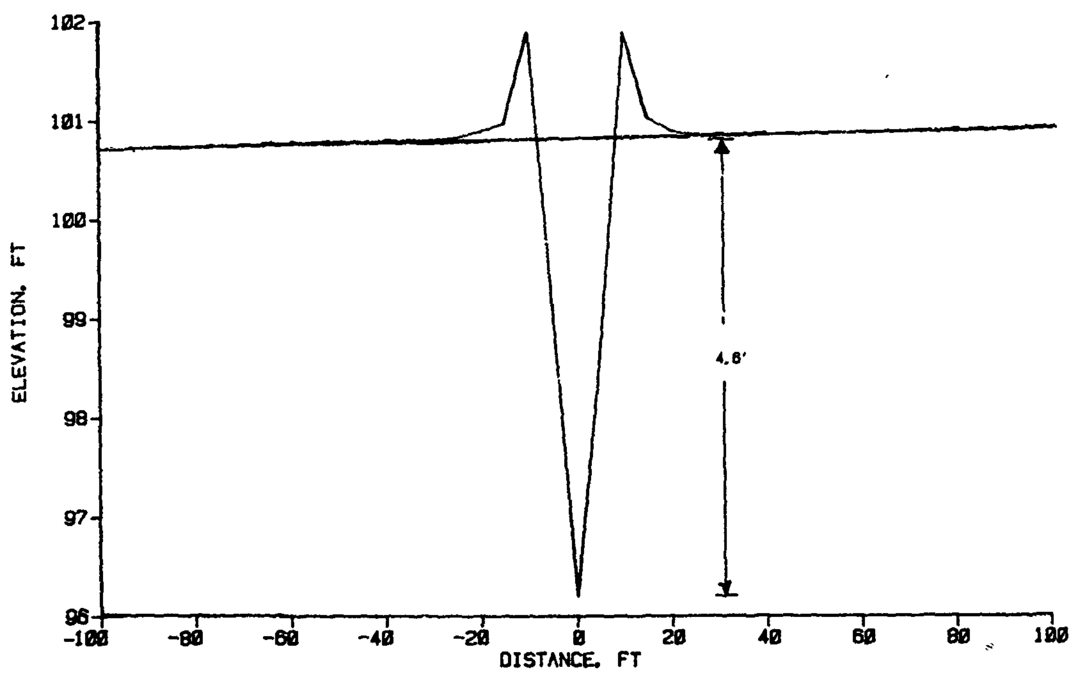


Figure 7. Runway surface before and after crater was exploded in a west-east direction, FOD cover repair

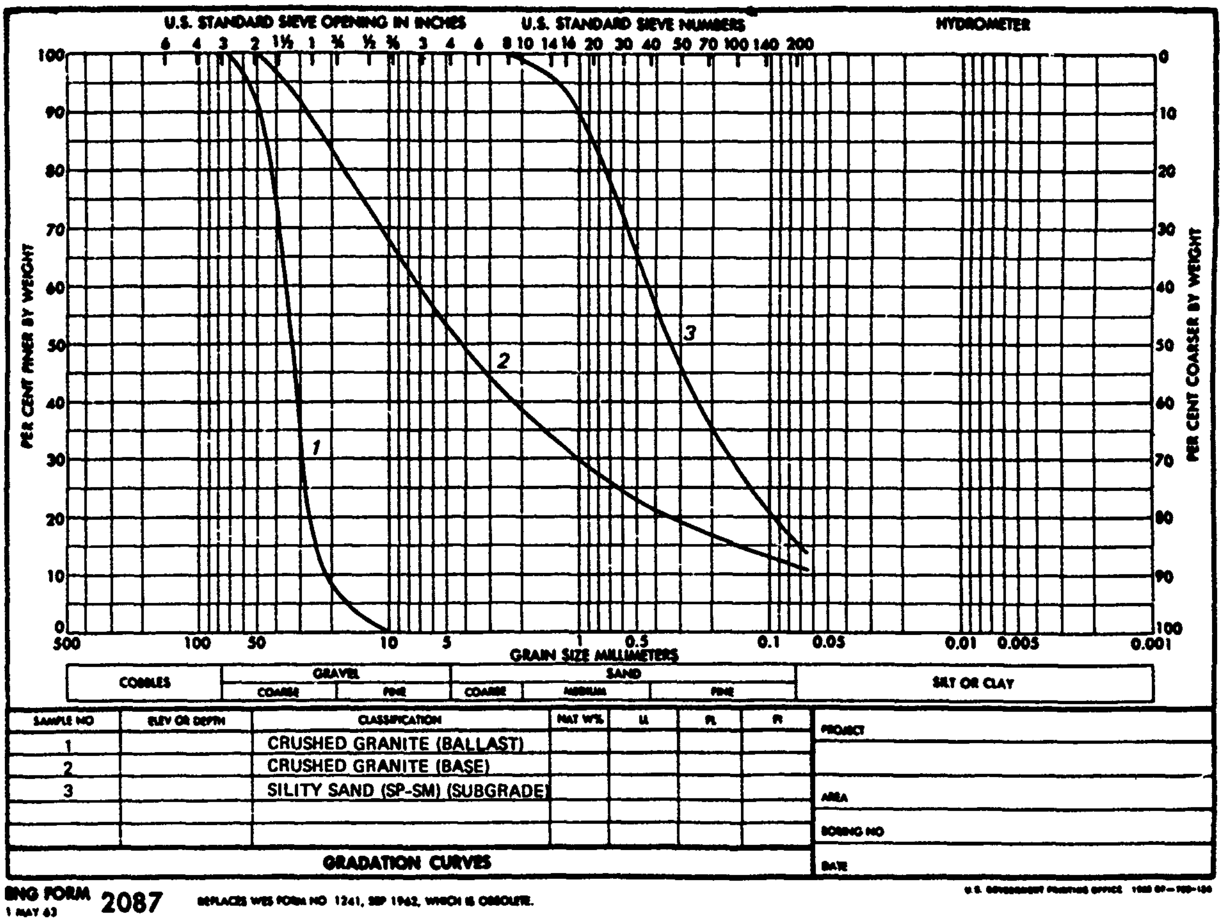


Figure 8. Gradation of material in the FOD cover repair

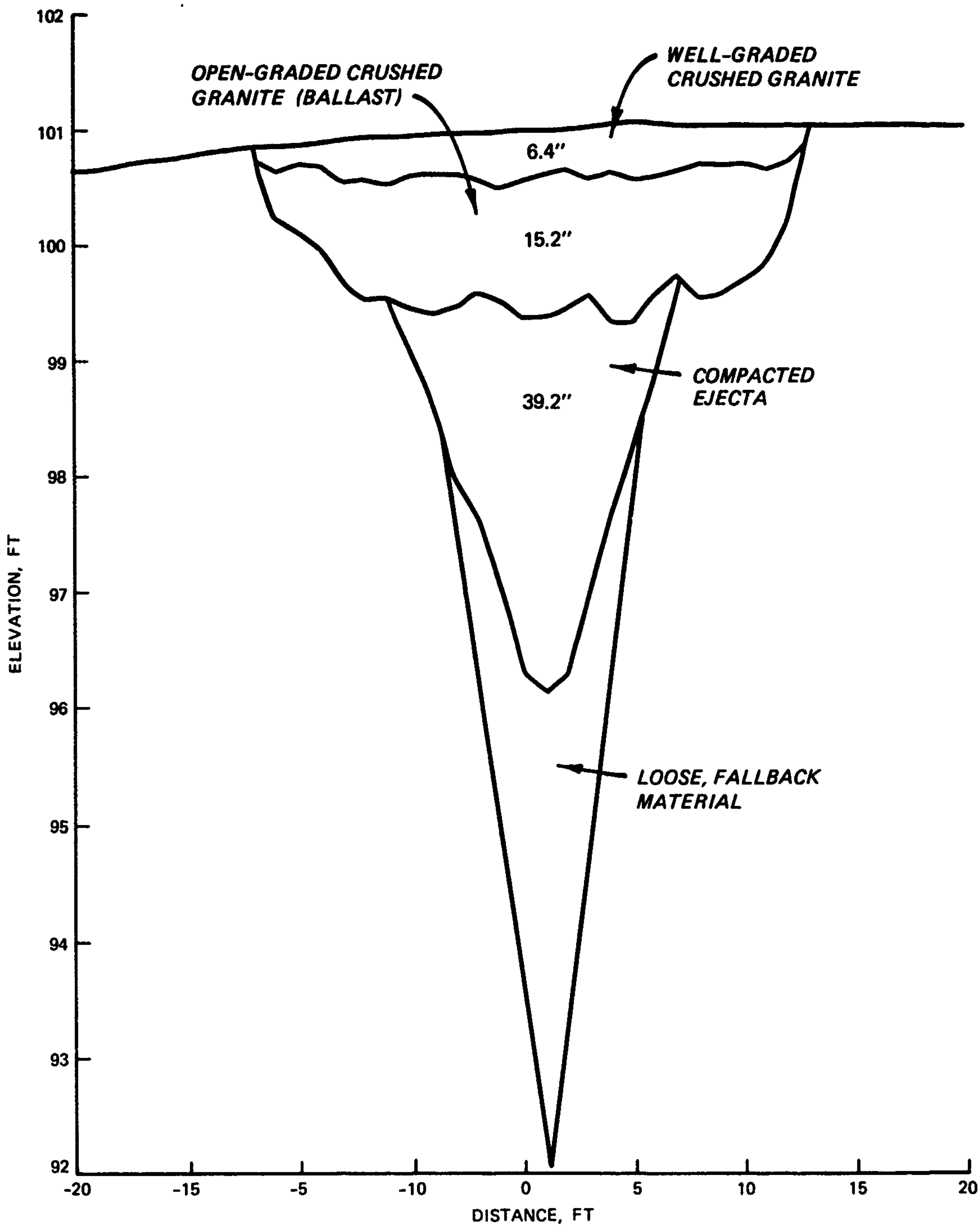


Figure 9. Thickness of materials used in the FOD cover repair, north-south direction

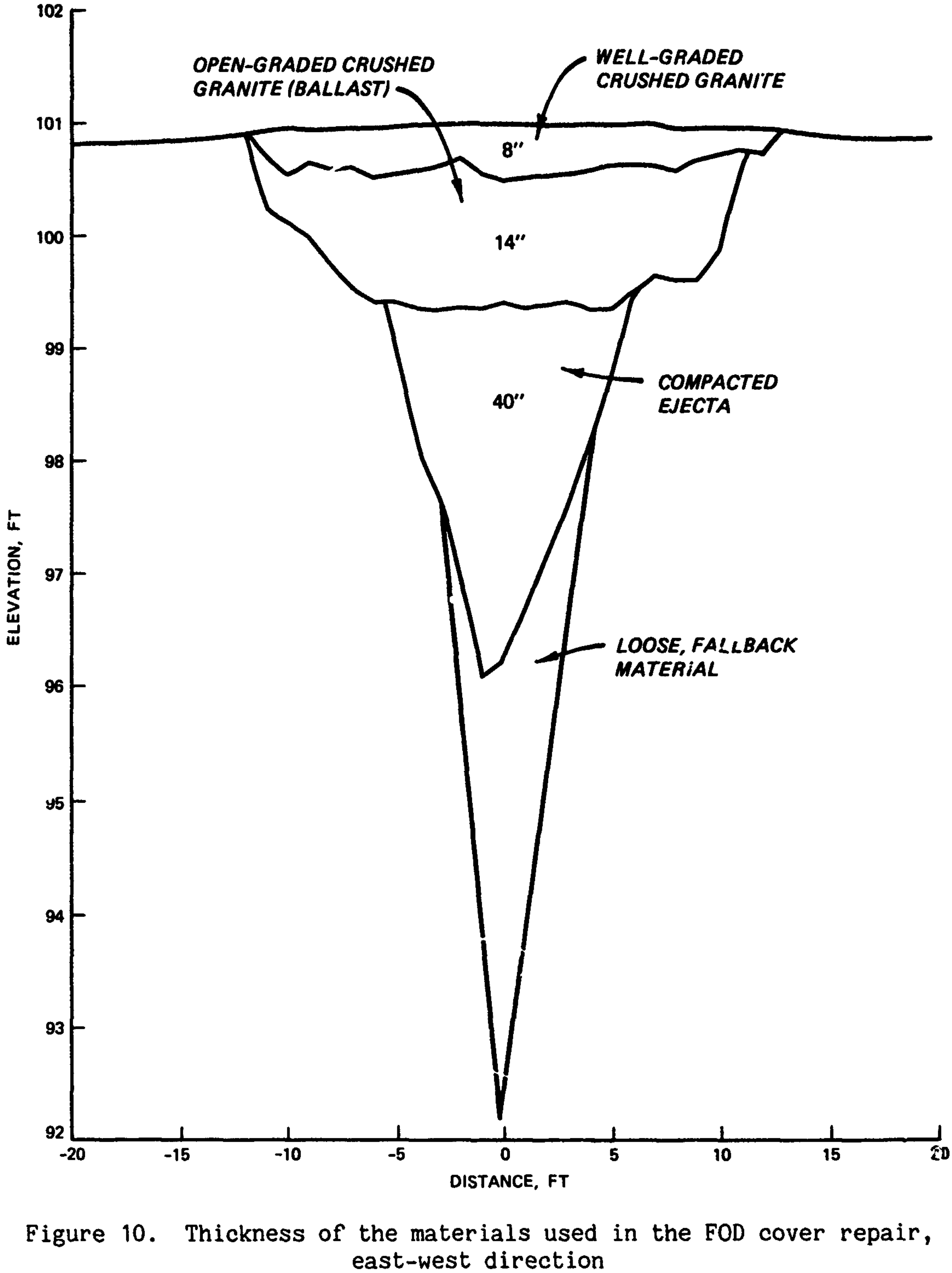


Figure 10. Thickness of the materials used in the FOD cover repair, east-west direction

then leveled with the motor grader to an elevation which was approximately 4 in. above the original grade of the runway surface. Compaction of the crushed granite was accomplished with five passes with a Bros Model VM-278 steel-wheeled double drum vibratory roller set at the high force level. The drums were 78 in. wide and 54 in. in diameter. The roller had a static weight of 25,000 lb, the maximum dynamic force was 21,000 lb per drum, and the maximum total applied force was 33,500 lb per drum. The rolling procedure consisted of five passes of the roller going forward and backward in the same path with both drums vibrating. After three roller passes the crushed granite was reshaped with the motor grader and then compacted with two more passes of the roller. During compaction the roller was operated on to the adjacent PCC to ensure compaction around the edge of the crater. This caused some cracking in the PCC outside the crater repair and additional upheaval at some cracks already there. The cracks were located at the east and west ends of the crater. CBR (Photo 20), density, and modulus of subgrade reaction, k (Photo 21), tests were performed on the crushed granite and results are shown in Table 2. Cross-section plots in Figures 9 and 10 show the thickness of the crushed granite after compaction, and Figure 11 shows laboratory compaction and CBR data for the well-graded crushed granite at a CE-55 compaction effort.

12. The FOD cover surfacing which was placed on the compacted base material was fabricated at Tyndall AFB, Tampa, Florida. It was a 0.25- to 0.375-in.-thick two-ply polyurethane fiberglass mat 36.5 ft long and 39.25 ft wide. The mat was fabricated with two layers of fiberglass woven mat (Style 4020) with approximately 1.5 lb of polyurethane applied per square foot. The mat was constructed with four "hinges" spaced across the mat. The mat was hinged so that it could be folded (8.5$\pm$ ft by 36.5 ft) for shipment. The width of the hinges varied from 5 to 7 in. and were constructed by omitting the polyurethane from the hinge areas during the initial fabrication of the mat. When the mat arrived at the test site, it was unfolded and the polyurethane was applied to the hinge areas, making the mat rigid and eliminating the hinges. Several damaged areas on the hinges were reinforced with fiberglass patches during this operation which occurred the week prior to the crater repair.

13. The FOD cover was placed over the crater repair with a military all-terrain fork lift (Photo 22). After the FOD cover was in place, it was anchored on each end of the crater with Wej-it 5/8- by 5-in. bolts using low

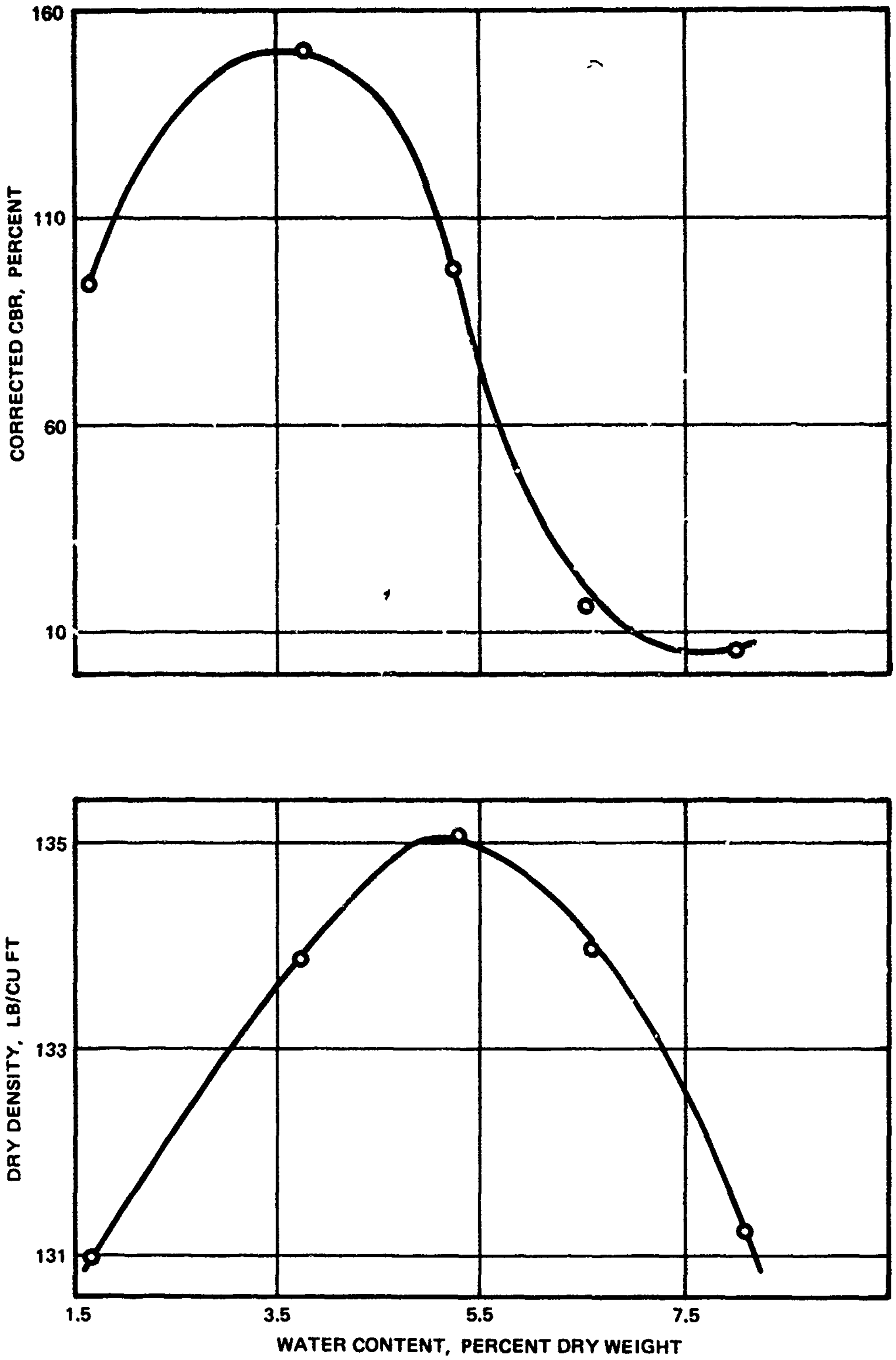


Figure 11. CE-55 compaction effort for the well-graded crushed granite

profile bushings spaced on 3-ft centers (Photo 23). Photo 23 also shows the electric hammer drill used for drilling the anchor holes in the PCC. The mat was not anchored on the sides.

PART III: TESTING AND BEHAVIOR UNDER TRAFFIC--PRECAST SLAB REPAIR (WEST CRATER)

Test Conditions and Procedures

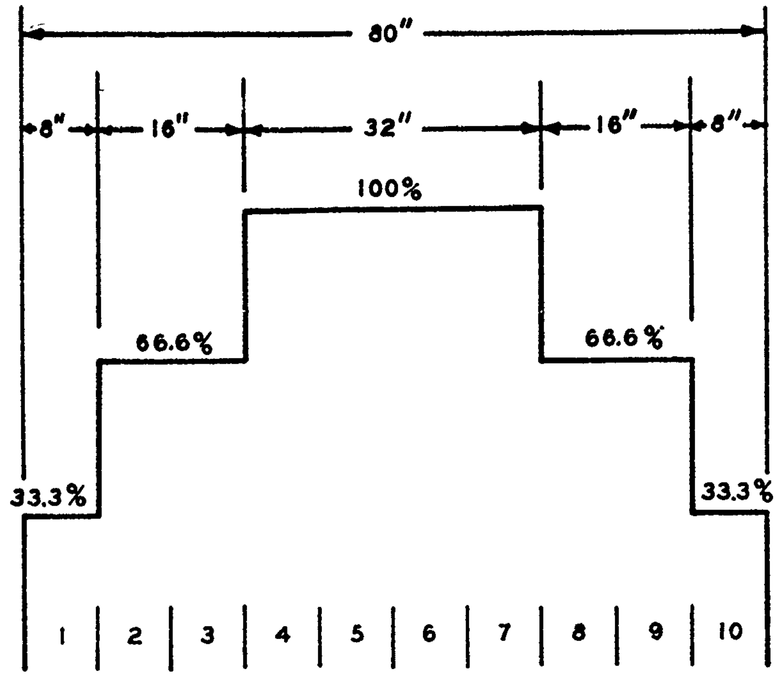
14. Traffic tests were performed on the 26.35- by 33.0-ft test section with an F-4 aircraft and with a specially designed load cart on two separate lanes within the test section. The test vehicles, test lanes, traffic patterns, and pavement conditions during traffic are discussed in the following paragraphs.

Test vehicles

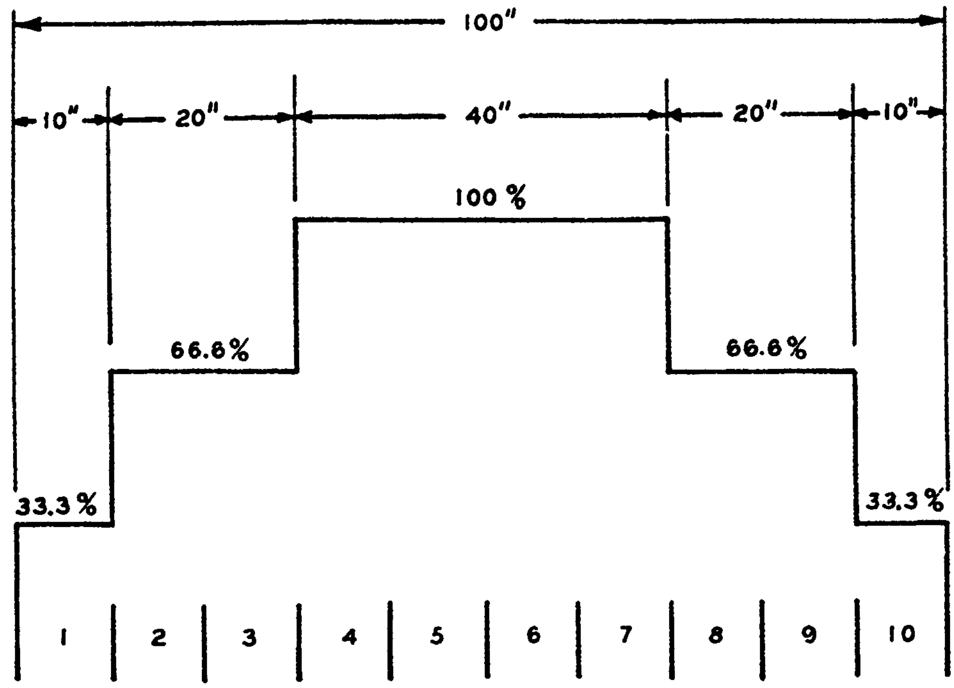
15. Traffic was applied to the precast slab crater repair with an F-4 aircraft and a specially designed single-wheel test cart (Photo 24) which simulated F-4 and F-15 aircraft traffic. The test cart was equipped with an F-4 tire inflated to 265 psi and loaded to 27,000 lb for F-4 traffic and with an F-15 tire inflated to 355 psi and loaded to 30,000 lb for F-15 traffic.

Traffic patterns and test lanes

16. The two traffic patterns shown in Figure 12 were used in applying the test cart traffic in the F-15 and F-4 traffic lanes (Figure 13). The traffic pattern widths were varied depending on the tire print width in order to get the desired distribution of traffic over the width at the respective lane. The F-15 load cart traffic was distributed in a traffic lane 80 in. wide to simulate the distribution normally encountered in the actual aircraft takeoffs and landings. The traffic sequence started at one side of the lane with traffic applied forward and backward in the same path for the length of the traffic lane. The path of the cart was then shifted laterally 8 in. (the width of tire print) on each successive forward trip. The full width of the traffic lane (80 in.) was trafficked in this manner, resulting in all points being subjected to two coverages of a loaded tire. The interior 64 in. of the traffic lane was then trafficked for two additional coverages and then the center 32 in. received two additional coverages. This traffic pattern, shown in Figure 12, required 44 passes of the load cart and resulted in a maximum of six coverages of the load wheel over the center 32 in. of the traffic lanes. This pattern of traffic was repeated until traffic was completed. Based on traffic distribution studies of aircraft on runways, the pass-coverage ratio



F-15 TRAFFIC PATTERN



F-4 TRAFFIC PATTERN

Figure 12. Traffic distribution patterns for the F-15 and F-4 load carts

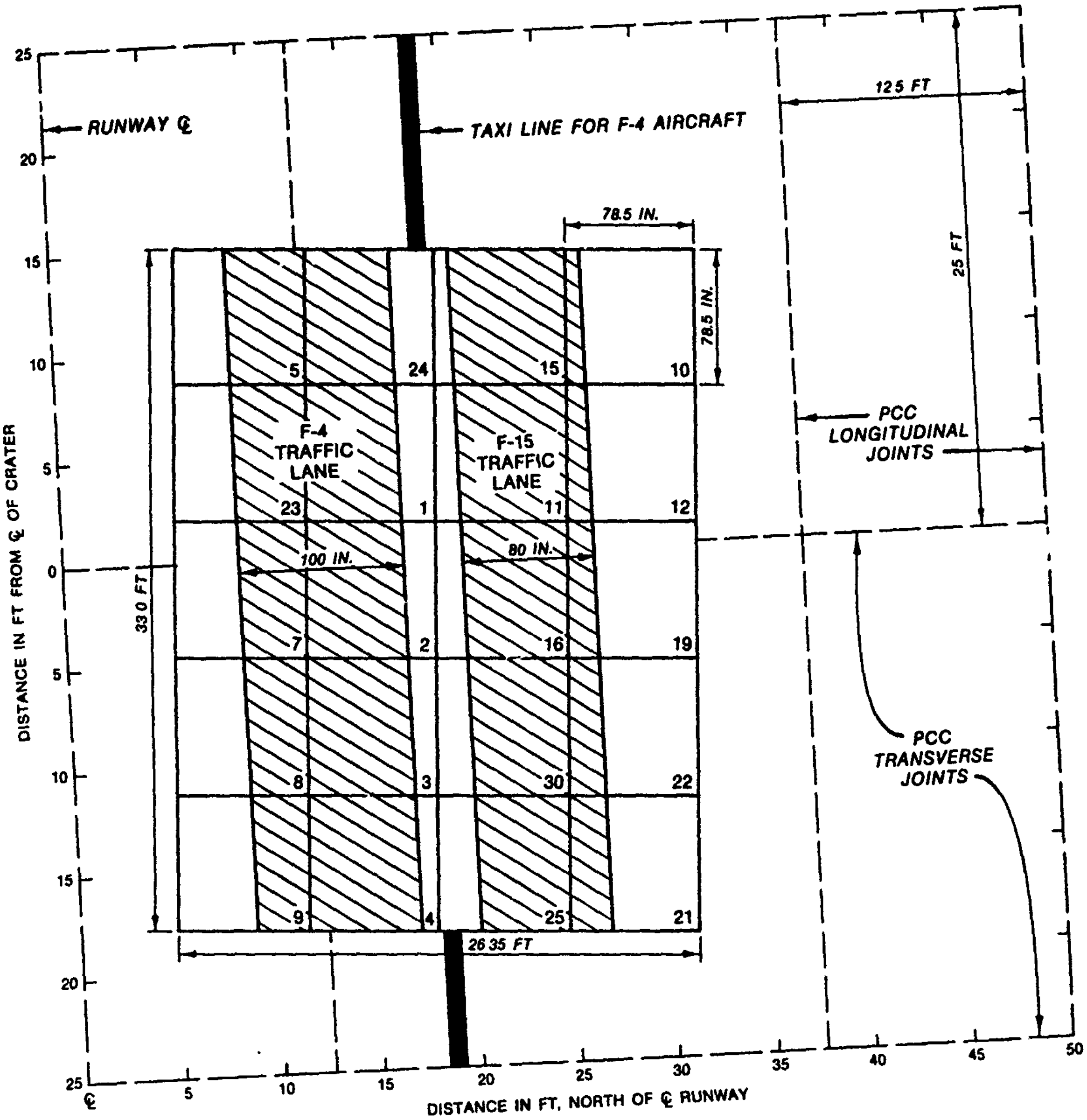


Figure 13. Layout of precast slab repair

for the F-15 aircraft is 9.46.* Thus, one coverage of traffic is equivalent to 9.46 takeoffs and/or landings on a runway. The F-4 load cart traffic was applied in the same manner as was the F-15 traffic. However, the load cart was shifted laterally 10 in. (the width for the F-4 tire) instead of the 8 in. for the F-15 traffic. This resulted in a 100-in.-wide F-4 traffic lane. Figure 12 shows the traffic pattern for the F-4 traffic. The pass-coverage ratio for the F-4 is 8.58.* The F-4 aircraft traffic consisted of taxi runs,

* D. N. Brown and O. O. Thompson. 1973. "Lateral Distribution of Aircraft Traffic," Miscellaneous Paper S-73-56, US Army Engineer Waterways Experiment Station, Vicksburg, Miss.

touch-and-go's on or close to the crater repair, takeoffs (from touch-and-go) with the after burners in a takeoff attitude over the repair, and braking runs.

Behavior of Precast Slabs during Traffic

17. Generally the sequence of test traffic applied to the crater repair was as follows: (a) proof-testing the entire width of the repair with the F-4 test cart, (b) F-4 aircraft operations, (c) F-15 test cart traffic, and (d) F-4 test cart traffic. Visual observations of the behavior of the precast slabs were recorded throughout the traffic test period of each test lane. These observations were supplemented by photographs. Level readings were taken on the pavement prior to and at intervals during traffic to show the development of permanent pavement deformation. Sag measurements were also made throughout the traffic period. Plate-bearing and other pertinent tests were conducted on the underlying pavement layers after traffic. The data obtained during the traffic tests are presented in the following paragraphs.

18. A layout of the crater repair is shown in Figure 13. Note that each slab is numbered. Slabs were numbered for identification of defects prior to placement; therefore, there is no order to the numbers on the slabs after placement. These defects are shown in Table 3. Photo 25 shows the crater repair prior to traffic. Surface roughness measurements taken before traffic are given in Table 4. The maximum sag measured was 0.5 in. Proof loading of the repair with the F-4 load cart was accomplished by driving the load cart across the crater repair with the load wheel located along the outside edge of the slabs in the outside (north) row of slabs. The load cart wheel was driven forward and backward in the same path. The load wheel was then shifted to the other (inside) edge on the same row of slabs and driven forward and backward in the same path and then shifted over to the next edge. This was repeated until each edge on each row had been proof loaded. After each edge had been loaded, the cart was driven with the load wheel passing forward and backward down the center of the slabs in each row. Considerable movement of the slabs was observed during the proof-testing of the crater repair. The most movement occurred when the load wheel was on the corner of a slab. There were no measurements taken during this initial proof loading; however, some of the slabs tipped at least 6 in. because the bottom edge of the slab could be seen

when the load wheel was on the opposite corner. The average slab movement was estimated to be approximately 3 in. During proof-testing the sag measurement along the south joint line increased from 0.25 to 1.50 in. (Table 4). After proof-testing, loaded (load tire on edge of slabs) sag measurements were made and the maximum sag measured (2.60 in.) occurred along the center joint line. As can be detected in Photos 26 and 27, tipping up to 3.25 in. was measured during the loaded sag tests. During the proof-testing, the sand placed between the slabs moved (fell) from between the slabs which resulted in load transfer at the joint and the slabs moving together. This lateral movement of the slabs causing close contact with each other along with consolidation of the underlying fill material probably reduced the potential for movement under traffic and minimized the joint roughness. After the proof-testing, three slabs were removed and releveled to reduce sag of the slabs during traffic tests. Only a small amount (about 2 shovelfuls) of the leveling course material had to be spread under the low corners of these three slabs to achieve a level condition.

19. The order of F-4 aircraft testing was taxi runs, touch-and-go operations, and then braking runs. Run numbers and events are shown in Table 5. It should be noted that the main gear paths were shifted in order to be sure to test the slab repair with the maximum loads over the edges of the slabs representing the worst case. Surface roughness measurements recorded after runs 5, 13, 14, and 15 are shown in Table 4. The maximum roughness measured after runs 5, 13, 14, and 15 were 1.13, 1.80, 2.12, and 2.06 in., respectively. The measurement exceeding 2 in. after run 14 was considered cause for maintenance. However, since the aircraft was to be reconfigured for touch-and-go operations after one more run, it was decided to shift the taxi path back to the original and proceed. Thus, the main gear did not traverse the peak sag and this also explains the decreased sag measurement after run 15. After run 15 the aircraft was reconfigured for touch-and-go operations and the slabs were inspected for defects for the first time since placement. Results of this inspection indicated eight slabs contained cracks or breaks and six slabs contained minor spalling. (Two slabs contained both cracks and spalls.) Locations of these defects are shown in Figure 14. Eight of the twelve slabs contained defects before traffic was applied (Table 3). Nine slabs exhibited defects that were attributed to traffic. Profiles (in the direction of traffic) were taken at this time. There were 12 lines of data.

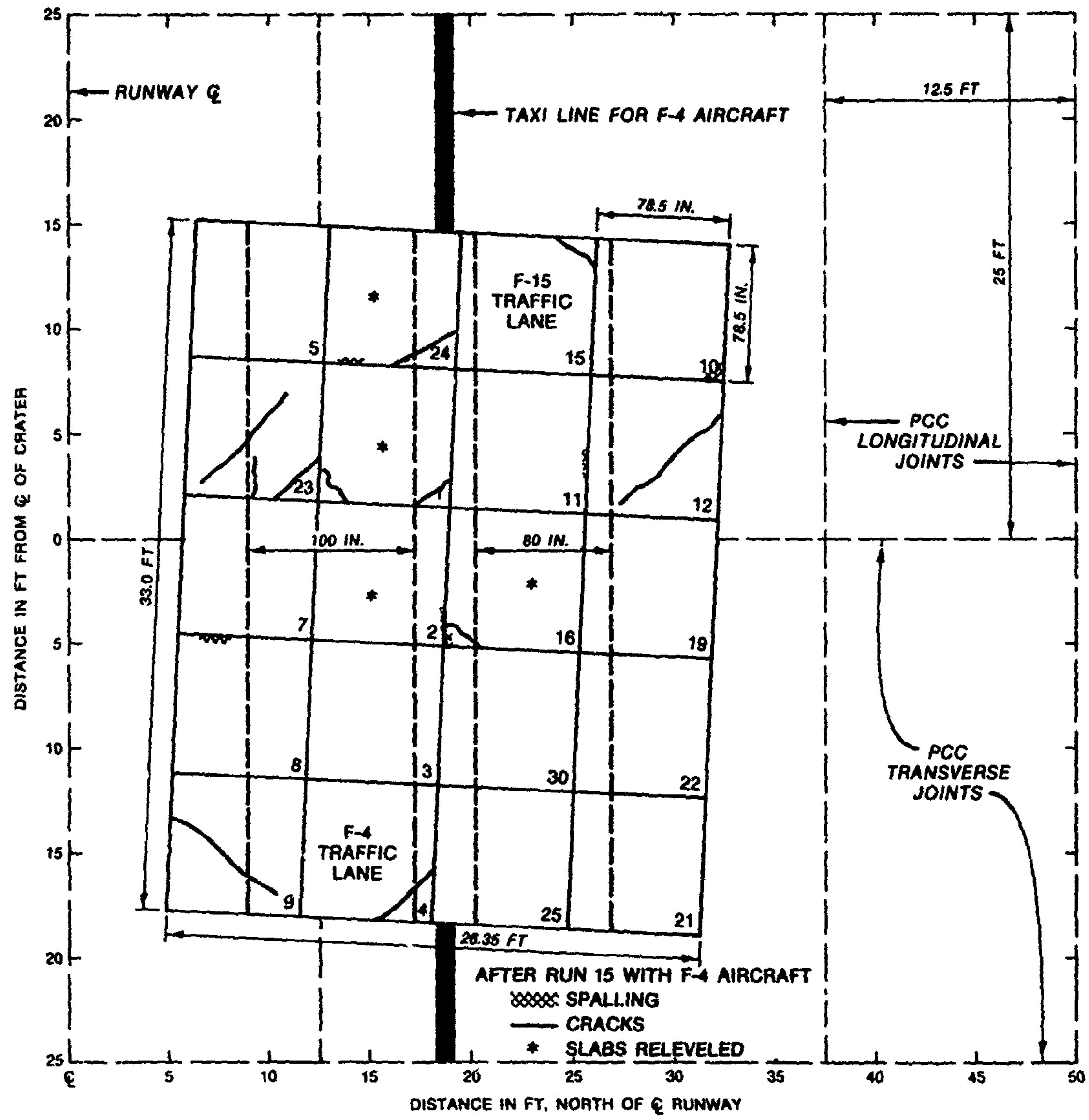


Figure 14. Defects in slabs after run 15, F-4 aircraft

Figure 15 shows the lines in relation to the crater repair. Figures 16 through 27 are profile plots comparing data taken before traffic (0 coverages) and data after run 15 of the aircraft.

20. After run 15 of the aircraft traffic, four slabs were removed and releveled (Figure 14). One slab was removed because the sag measurement exceeded the 2-in. sag criterion (Table 4) two were removed because the sag measurement was 1.75 in. (close to the 2-in. criterion), and one was removed to allow replacing of the Silikal patch (west end of crater) which failed under traffic.

21. F-4 aircraft traffic was continued with touch-and-go and braking

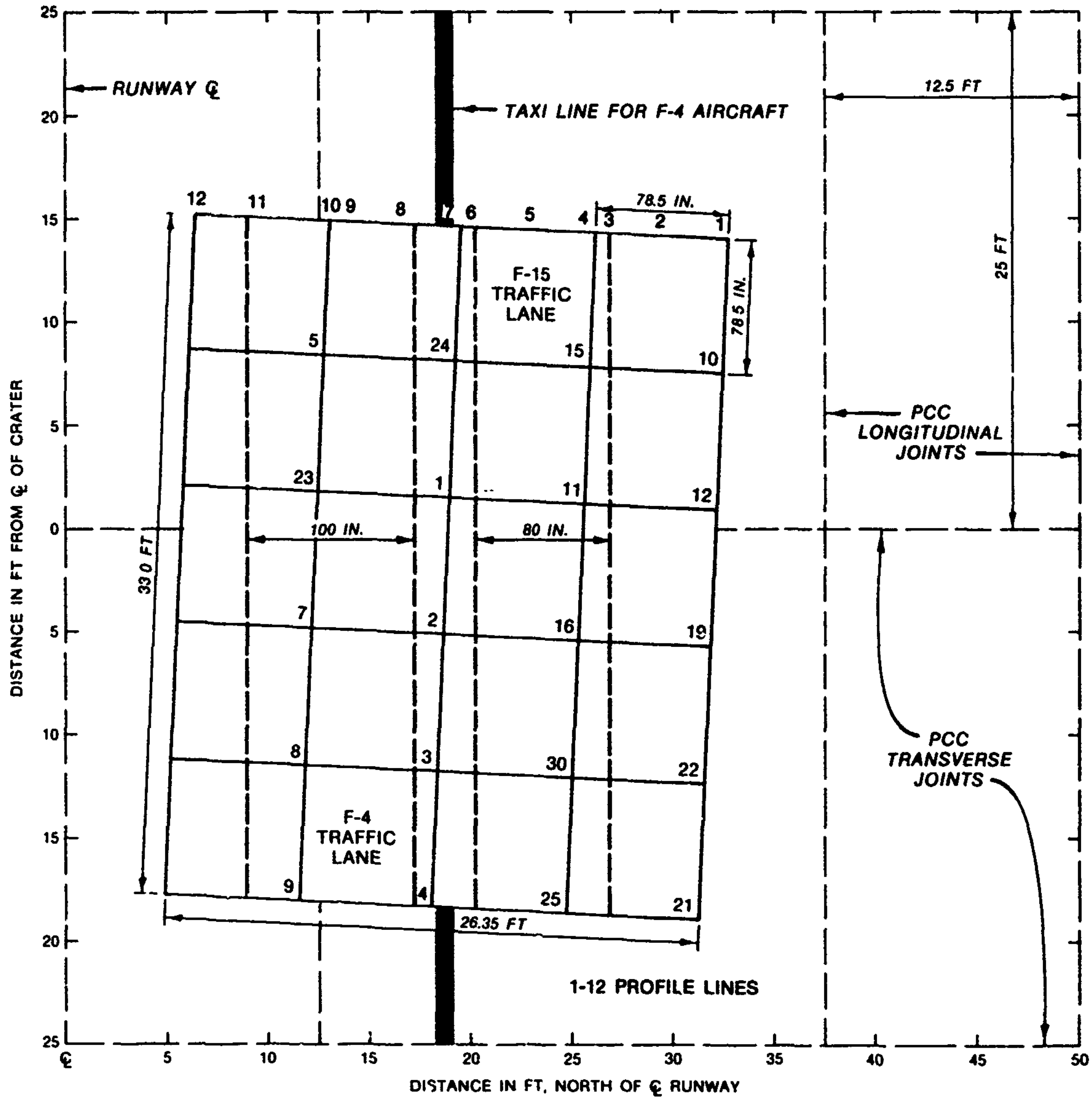


Figure 15. Profile and cross-section data lines

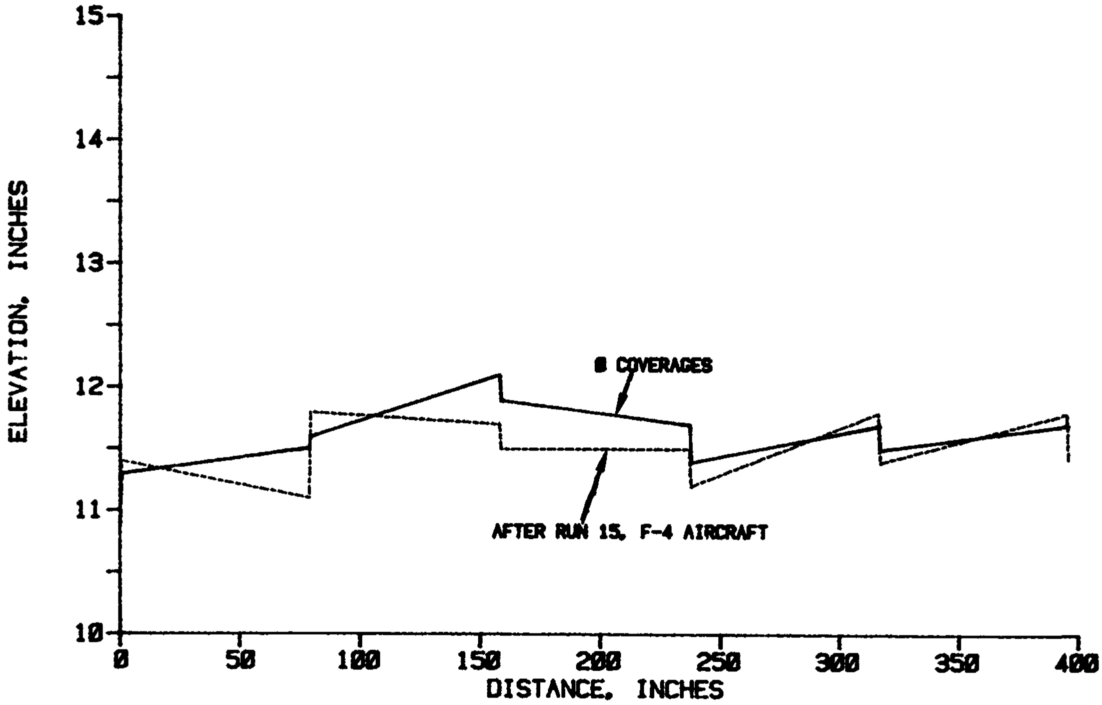


Figure 16. Line 1, profile, precast slab repair after F-4 traffic, run 15

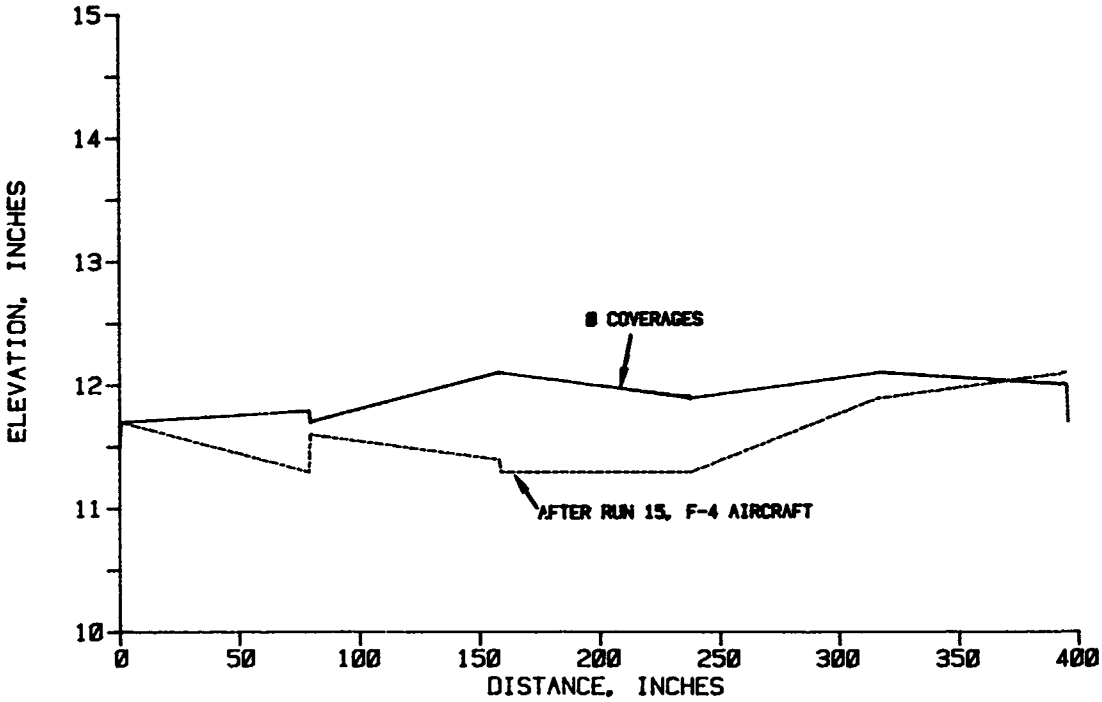


Figure 17. Line 2, profile, precast slab repair after F-4 traffic, run 15

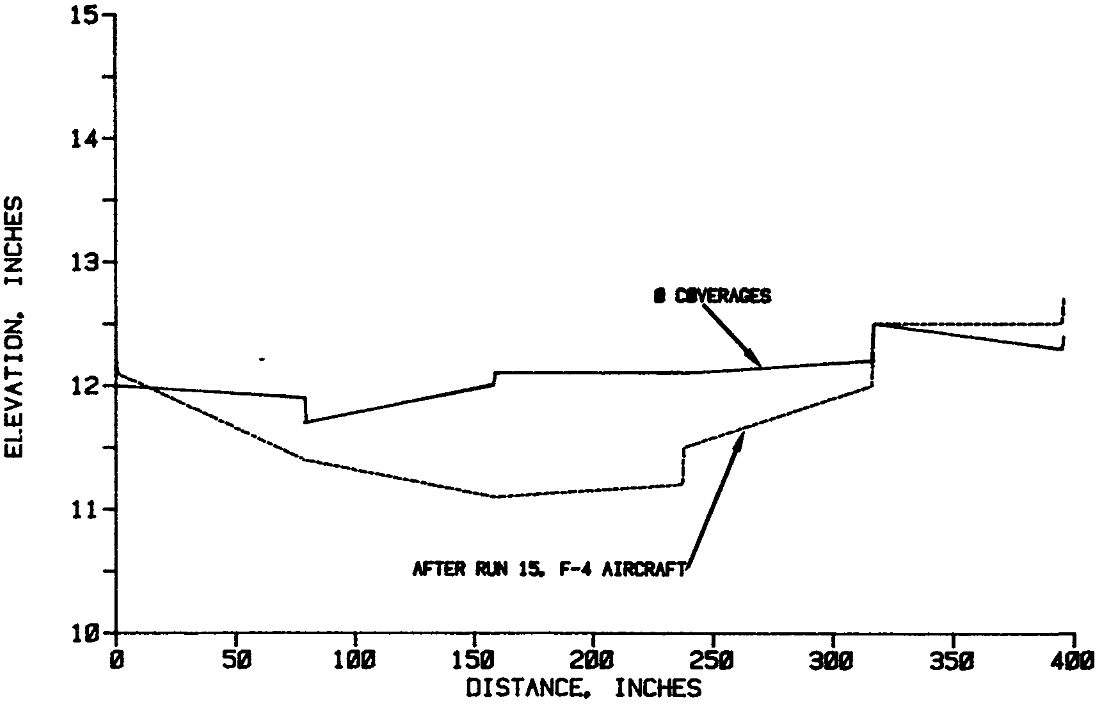


Figure 18. Line 3, profile, precast slab repair after F-4 traffic, run 15

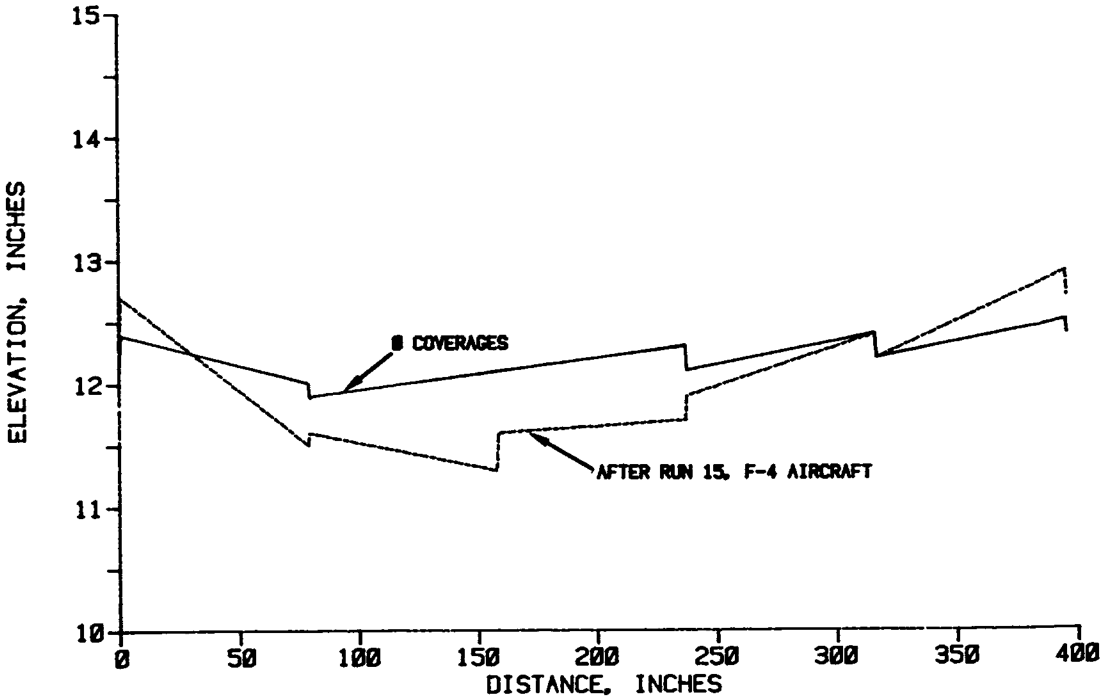


Figure 19. Line 4, profile, precast slab repair after F-4 traffic, run 15

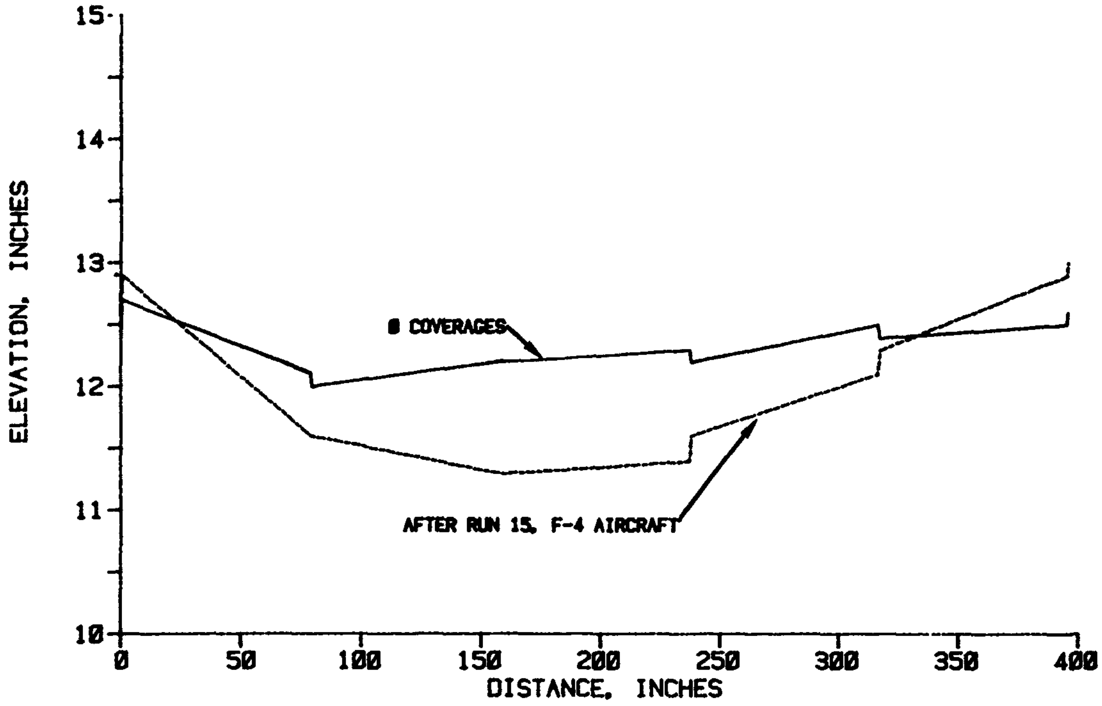


Figure 20. Line 5, profile, precast slab repair after F-4 traffic, run 15

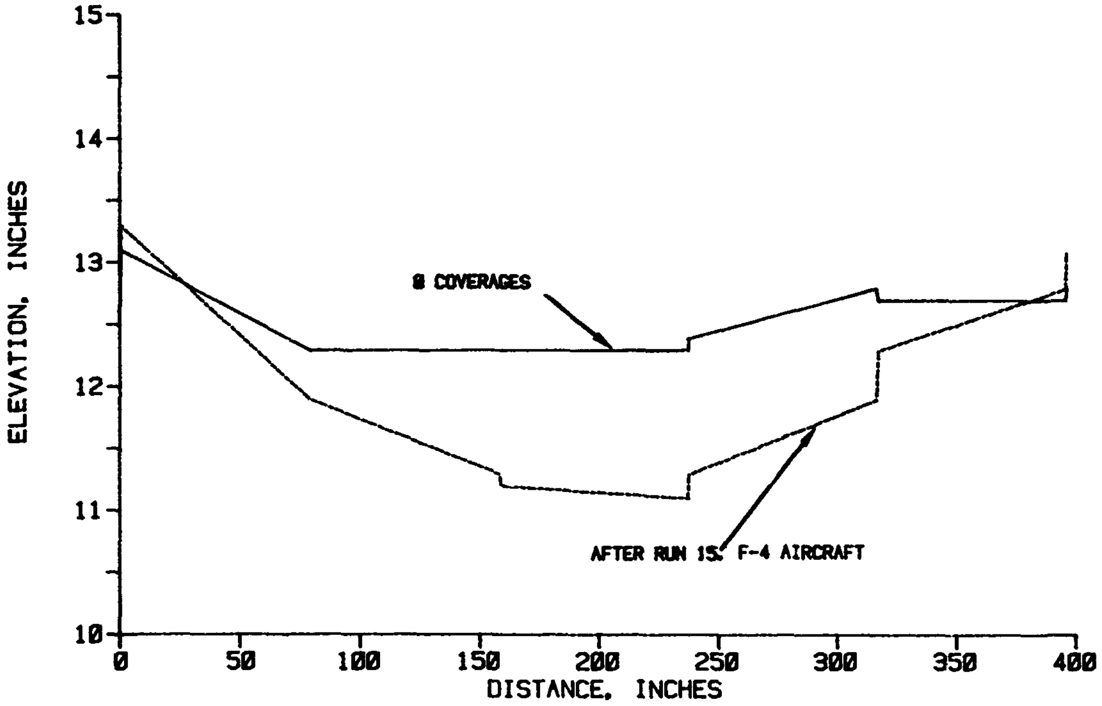


Figure 21. Line 6, profile, precast slab repair after F-4 traffic, run 15

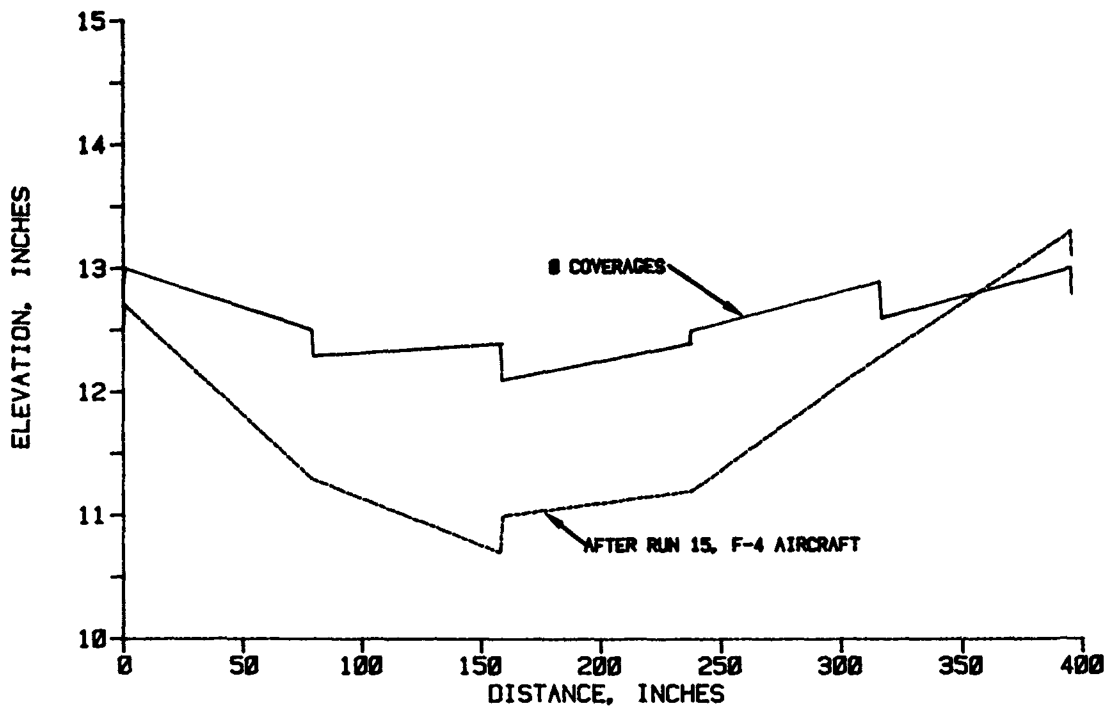


Figure 22. Line 7, profile, precast slab repair after F-4 traffic, run 15

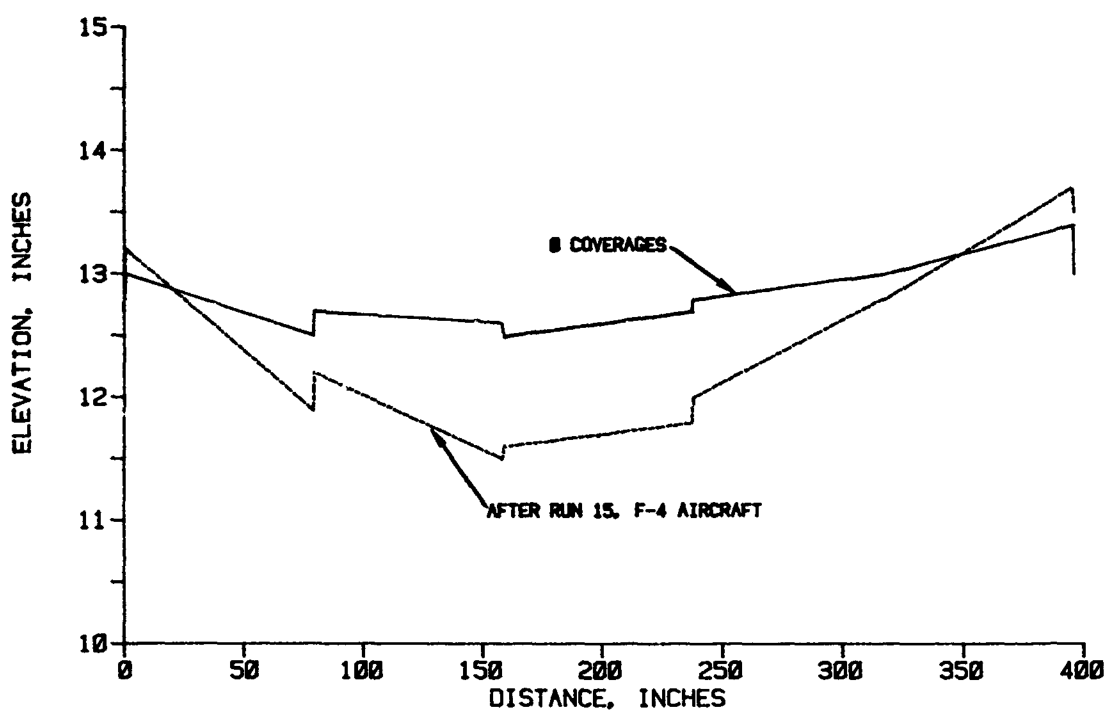


Figure 23. Line 8, profile, precast slab repair after F-4 traffic, run 15

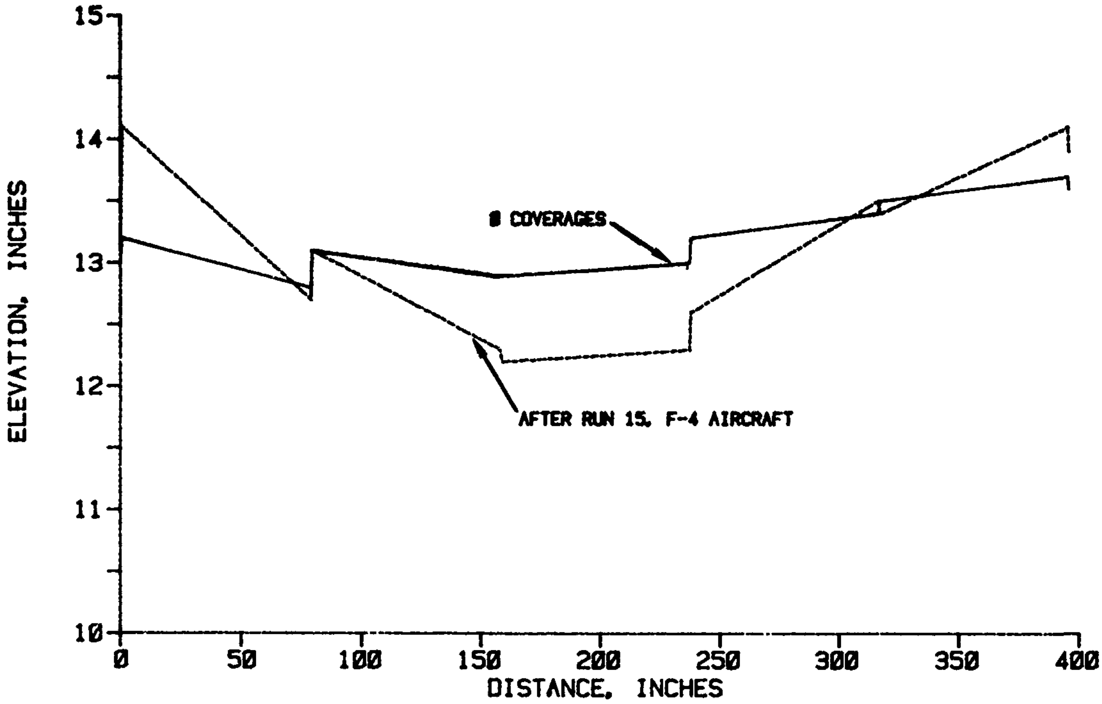


Figure 24. Line 9, profile, precast slab repair after F-4 traffic, run 15

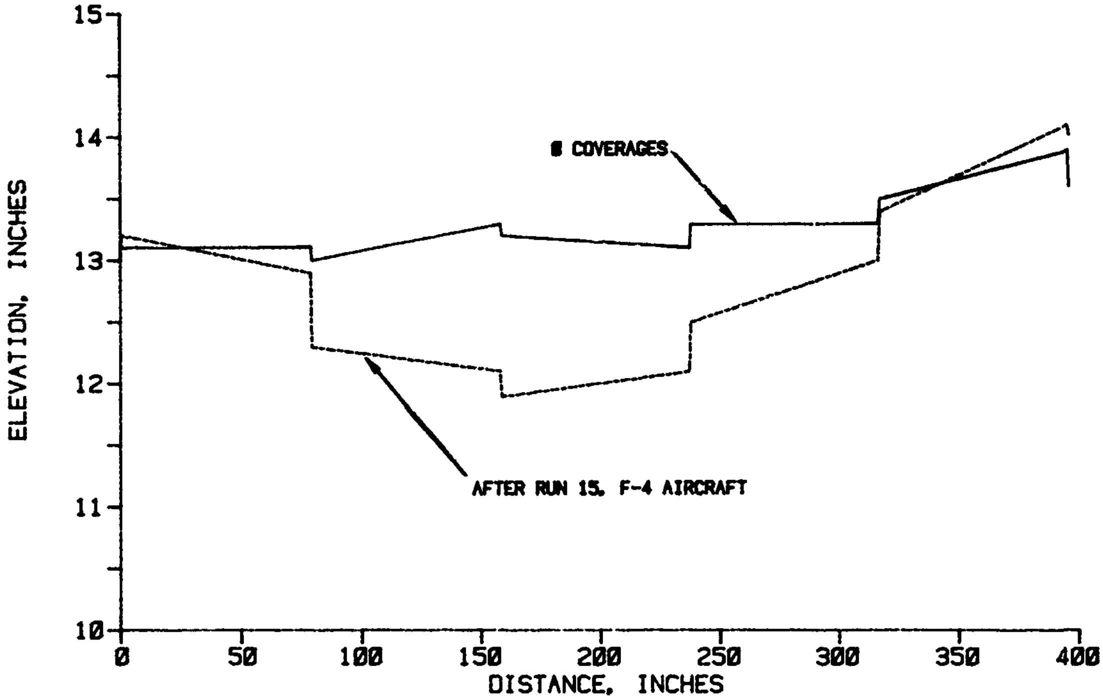


Figure 25. Line 10, profile, precast slab repair after F-4 traffic, run 15

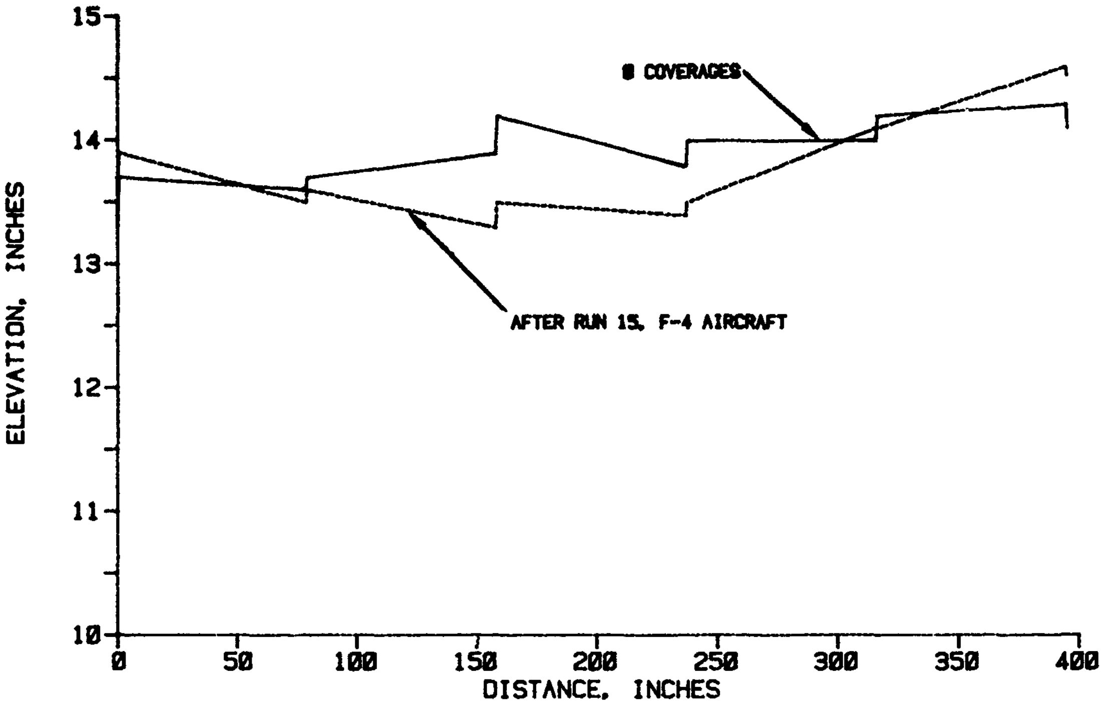


Figure 26. Line 11, profile, precast slab repair after F-4 traffic, run 15

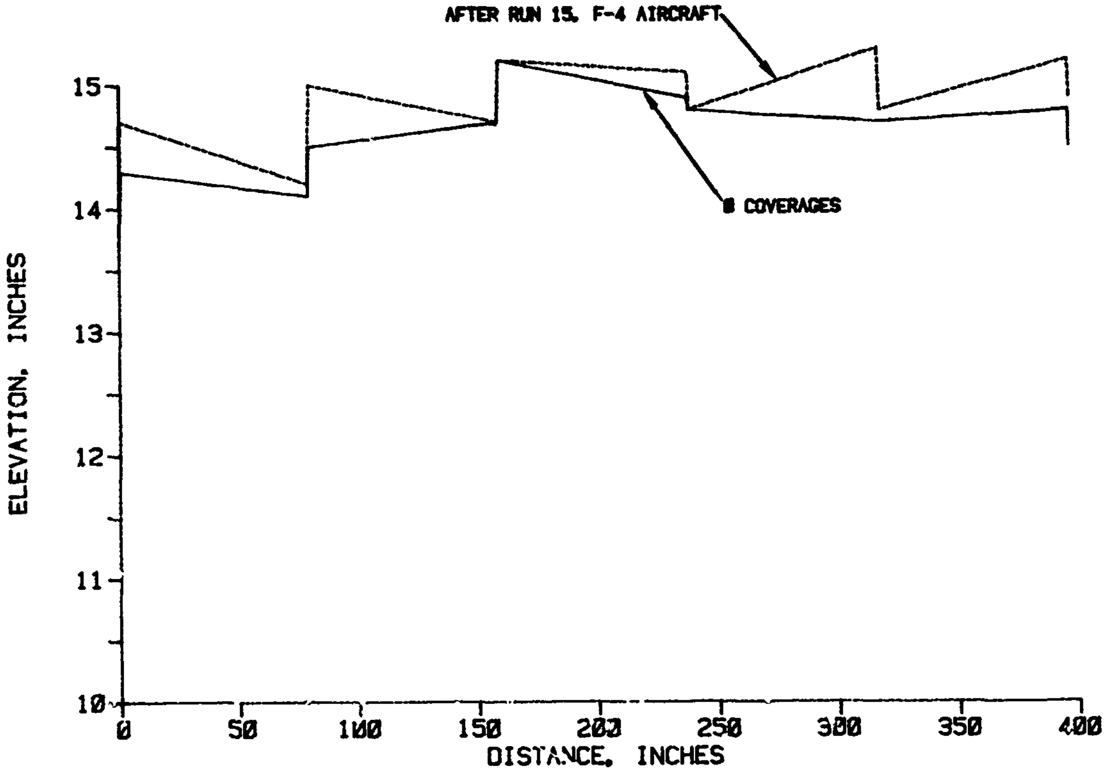


Figure 27. Line 12, profile, precast slab repair after F-4 traffic, run 15

runs (Table 5). These runs presented no apparent problem for the repair technique. Photo 28 shows the crater repair after all of the aircraft test runs. Note that rubber was left across the crater repair by the touch-and-go traffic. Figures 28 through 34 show profile data for the crater repair after the aircraft.

22. The F-4 aircraft test pilot comments about the precast slab repair were as follows:

- a. The roughest speeds for aircraft operations were 20 to 30 knots. At slower or faster speeds, there was not a roughness concern.
- b. At the 20- to 30-knot speed range, the aircraft not only bounced but also moved in a side-to-side rocking motion. This was considered not to be a major problem but was noticeable.
- c. Sag was not a problem.
- d. Touch-and-go operations felt the same for all surfaces, indistinguishable from normal landing impact.

23. After the aircraft traffic was completed, the F-15 load cart traffic lane (80 in. wide) was laid out (Figure 13) and traffic was applied. After two coverages, the maximum sag measurement was 1.75 in. located on the joint line inside of the traffic lane. Figure 35 shows the increase in defects (spalling and cracks) in the slabs since run 15 of the aircraft. The defects in the south two rows of slabs were caused by the F-4 aircraft after run 15. Spalling is visible in Photo 29. The spalling is located on slabs 15 and 16. As the traffic continued to 10 coverages, eight of the ten slabs in the traffic lane contained breaks or cracks (Figure 36). At this time, there was an increase in the spalling on the slabs, especially on slabs 30, 16, and 11. This would present an FOD problem due to the size of the particles (Photo 30). The maximum sag measurement at 10 coverages was 2.50 in. (Table 4) without the load wheel on the repair and 3.00 in. (failure criteria) with the load wheel on the repair (Photo 30). Using the pass-to-coverage ratio, this 10 coverages would be equivalent to 94.6 F-15 operations. It should be noted that the crater repair received eight passes of the F-4 aircraft traffic after maintenance was performed. Counting all F-4 traffic since construction, 23 passes with the aircraft and two coverages with the F-4 load cart (equivalent to 17.2 aircraft operations) were applied. Figures 28 through 34 show profile data for the crater repair after the 10 coverages of the F-15 load cart compared to the data after aircraft traffic. After 14 coverages, the maximum

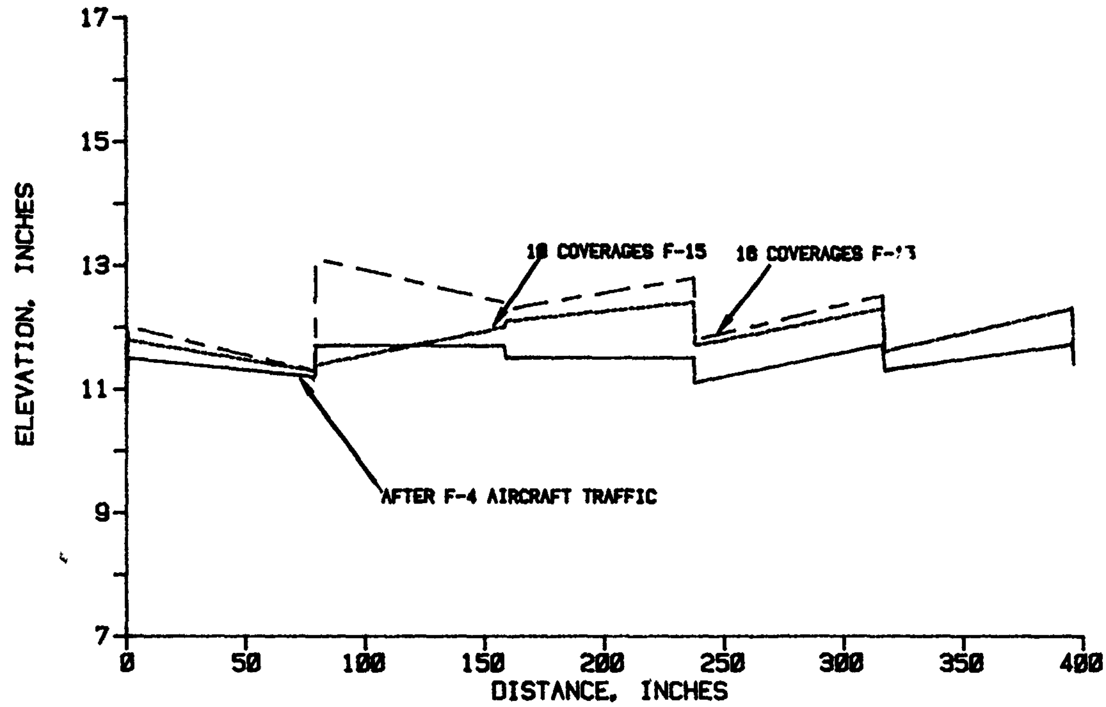


Figure 28. Line 1, profile, precast slab repair after F-15 traffic

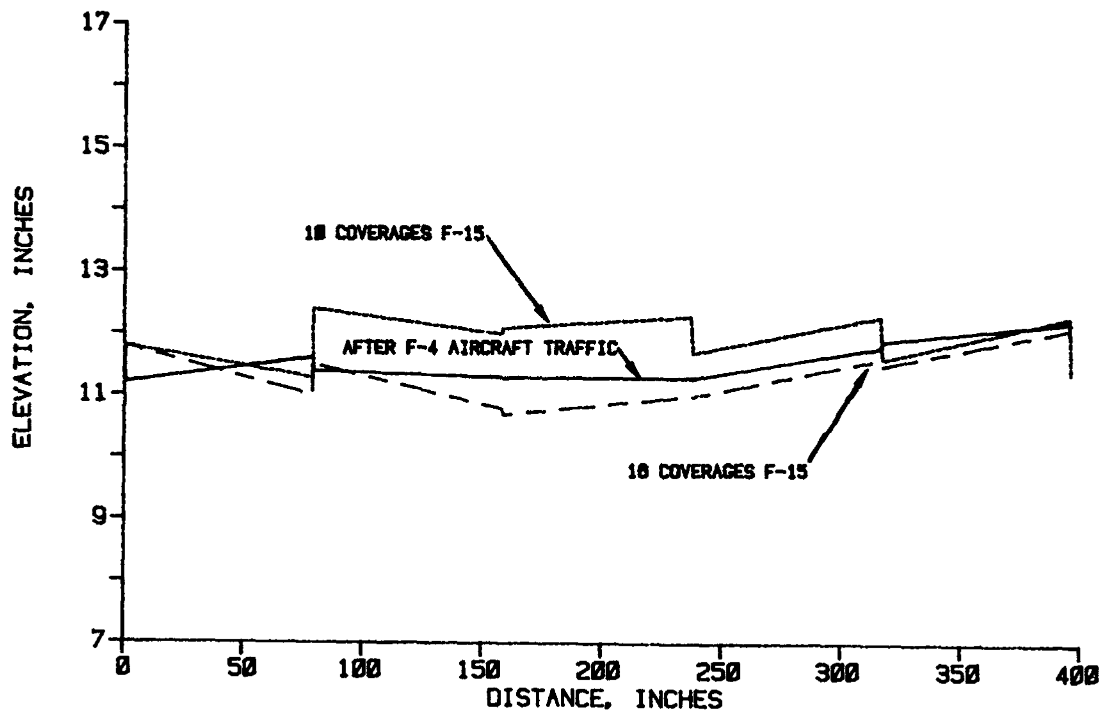


Figure 29. Line 2, profile, precast slab repair after F-15 traffic

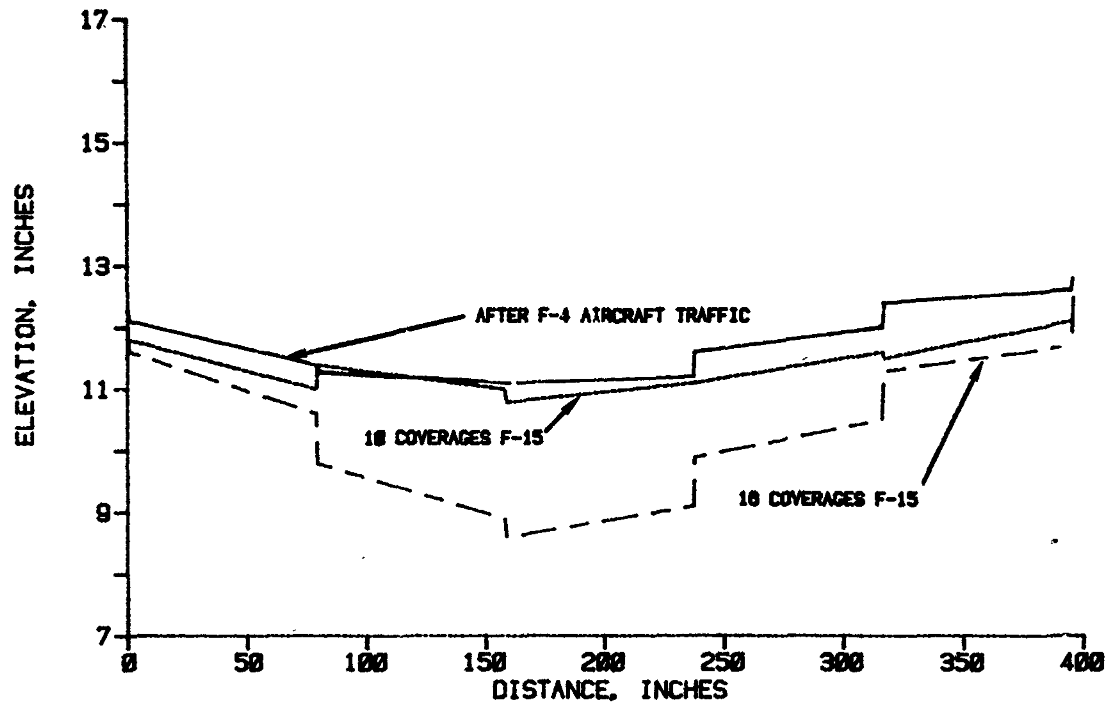


Figure 30. Line 3, profile, precast slab repair after F-15 traffic

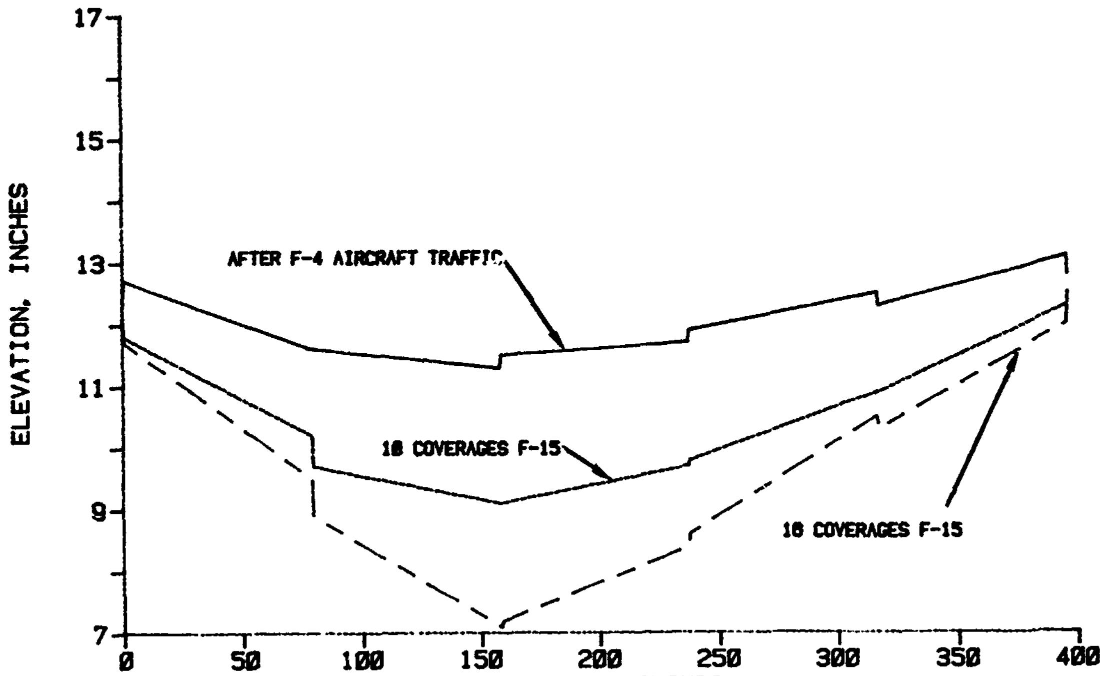


Figure 31. Line 4, profile, precast slab repair after F-15 traffic

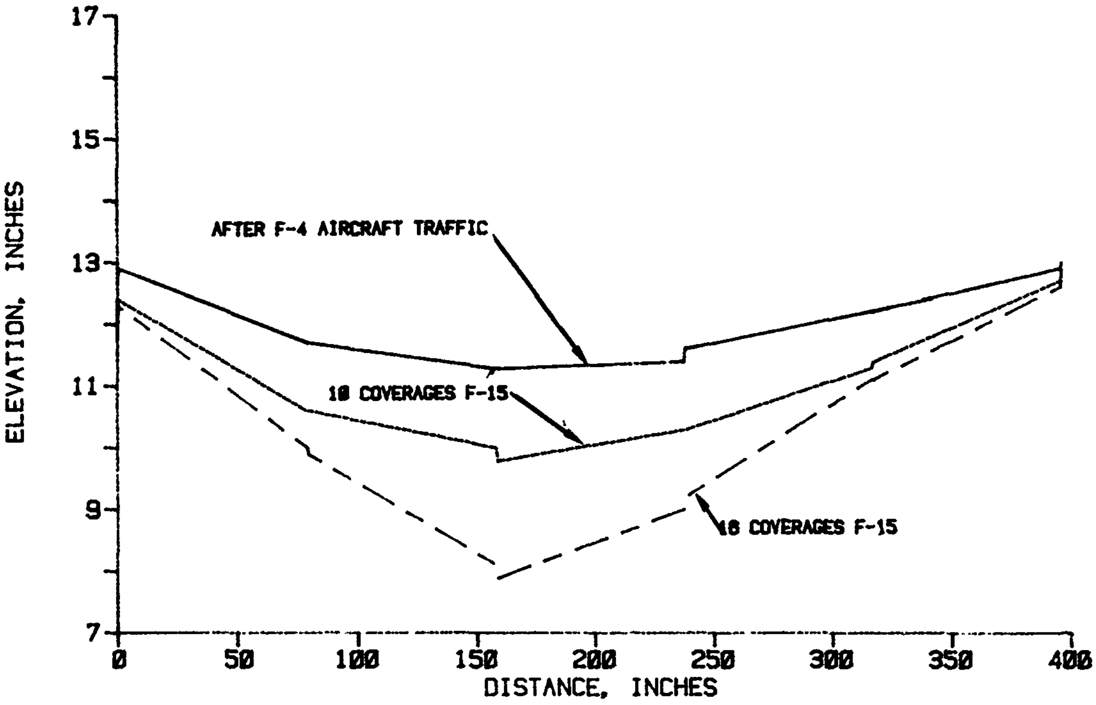


Figure 32. Line 5, profile, precast slab repair after F-15 traffic

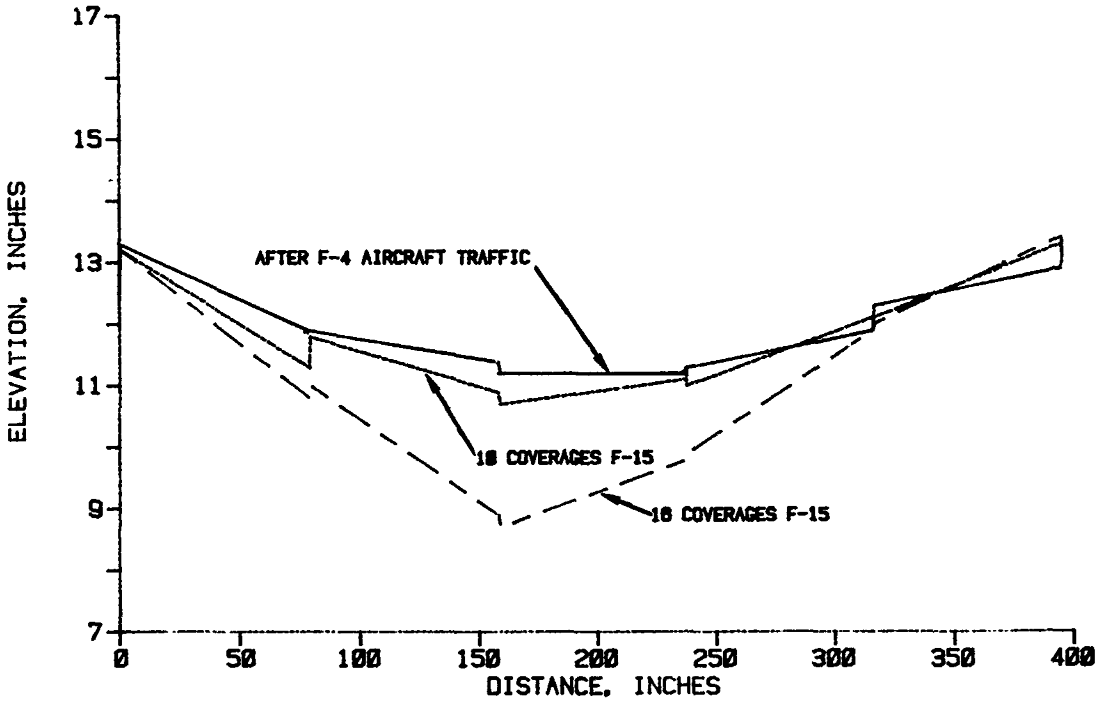


Figure 33. Line 6, profile, precast slab repair after F-15 traffic

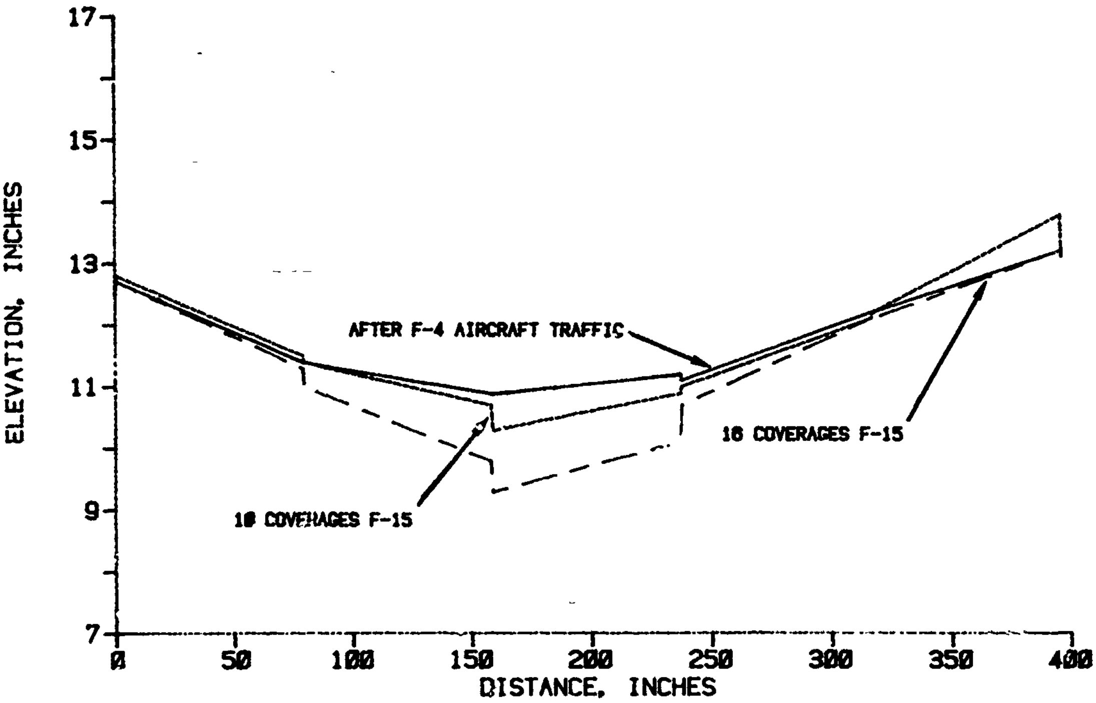


Figure 34. Line 7, profile, precast slab repair after F-15 traffic

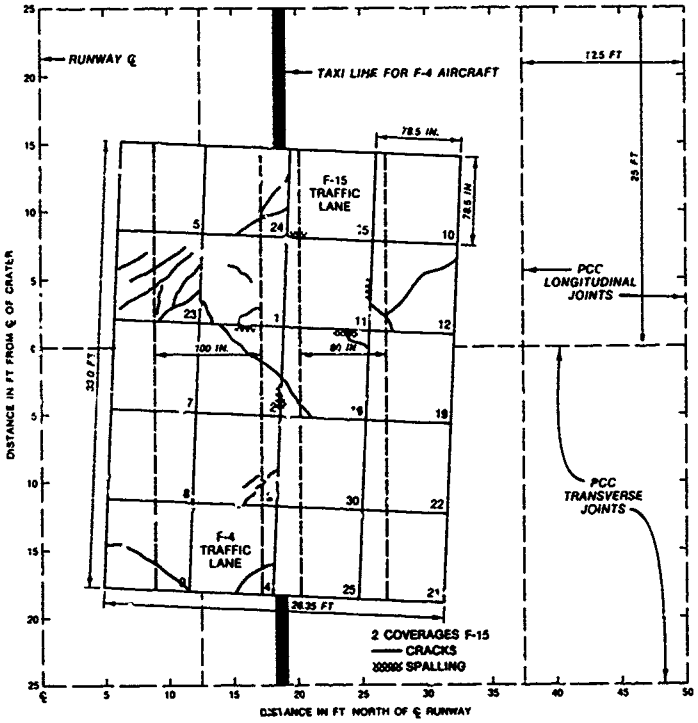


Figure 35. Defects in slabs after two coverages
of F-15 traffic

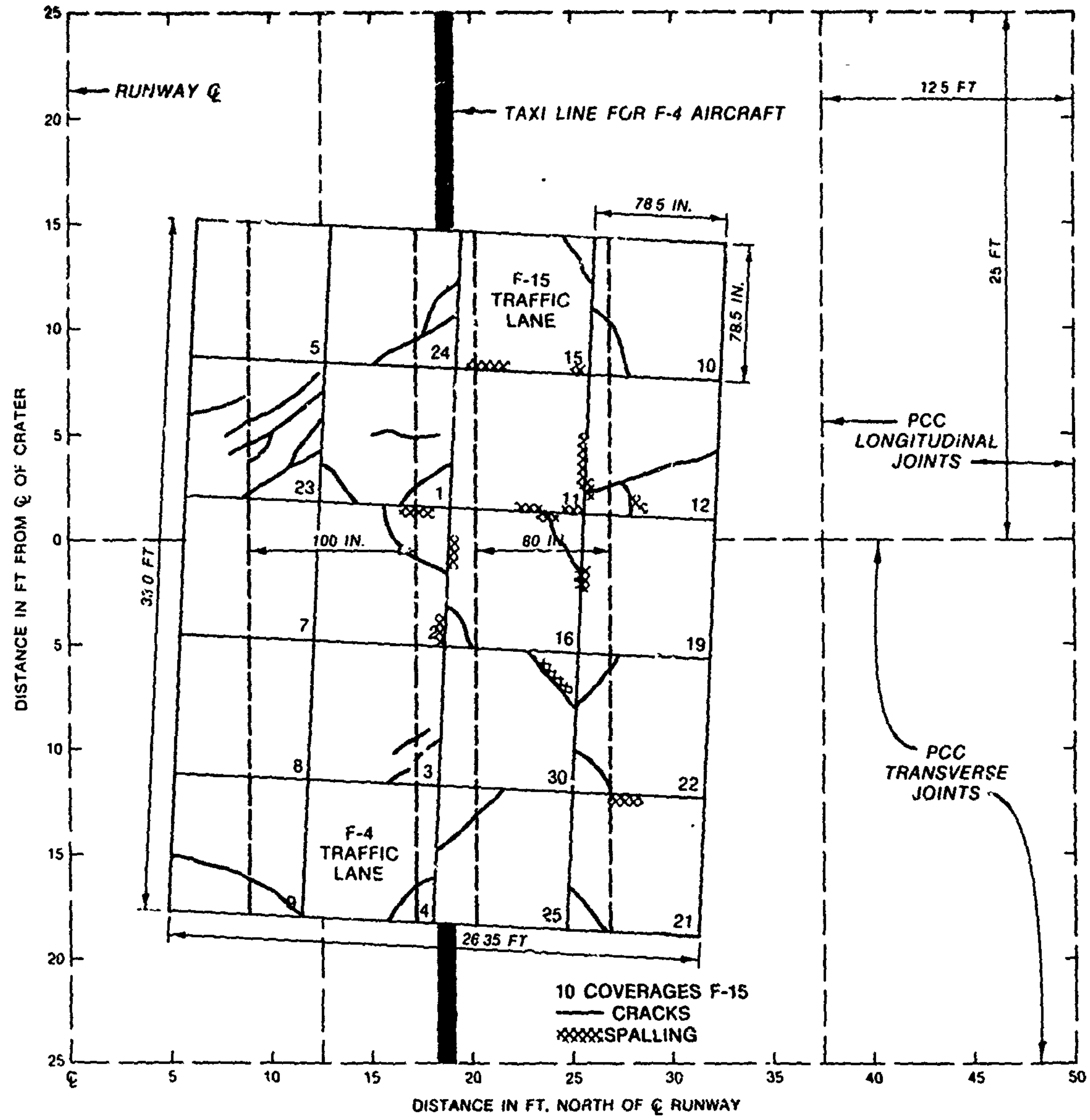


Figure 36. Defects in slabs after 10 coverages of F-15 traffic

sag measurement had increased to 4.63 in. (Table 4). This measurement was made without the load wheel on the repair. Photo 31 shows the sag measurement along with the spalling on slabs 16, 19, 11, and 12. Traffic was stopped after 16 coverages when a maximum sag of 5.25 in. was measured (Photo 32). The maximum sag measurements and the maximum joint difference (step) between the slabs recorded during all phases of traffic applied on the north side of the crater repair (F-15 traffic lane) are plotted and shown in Figure 37. Photo 33 is a general view of the traffic lane and Photo 34 shows the traffic with a 10-ft straightedge across the traffic lane after the 16 coverages. Figures 28 through 34 contain profile data after the 16 coverages. Figure 38

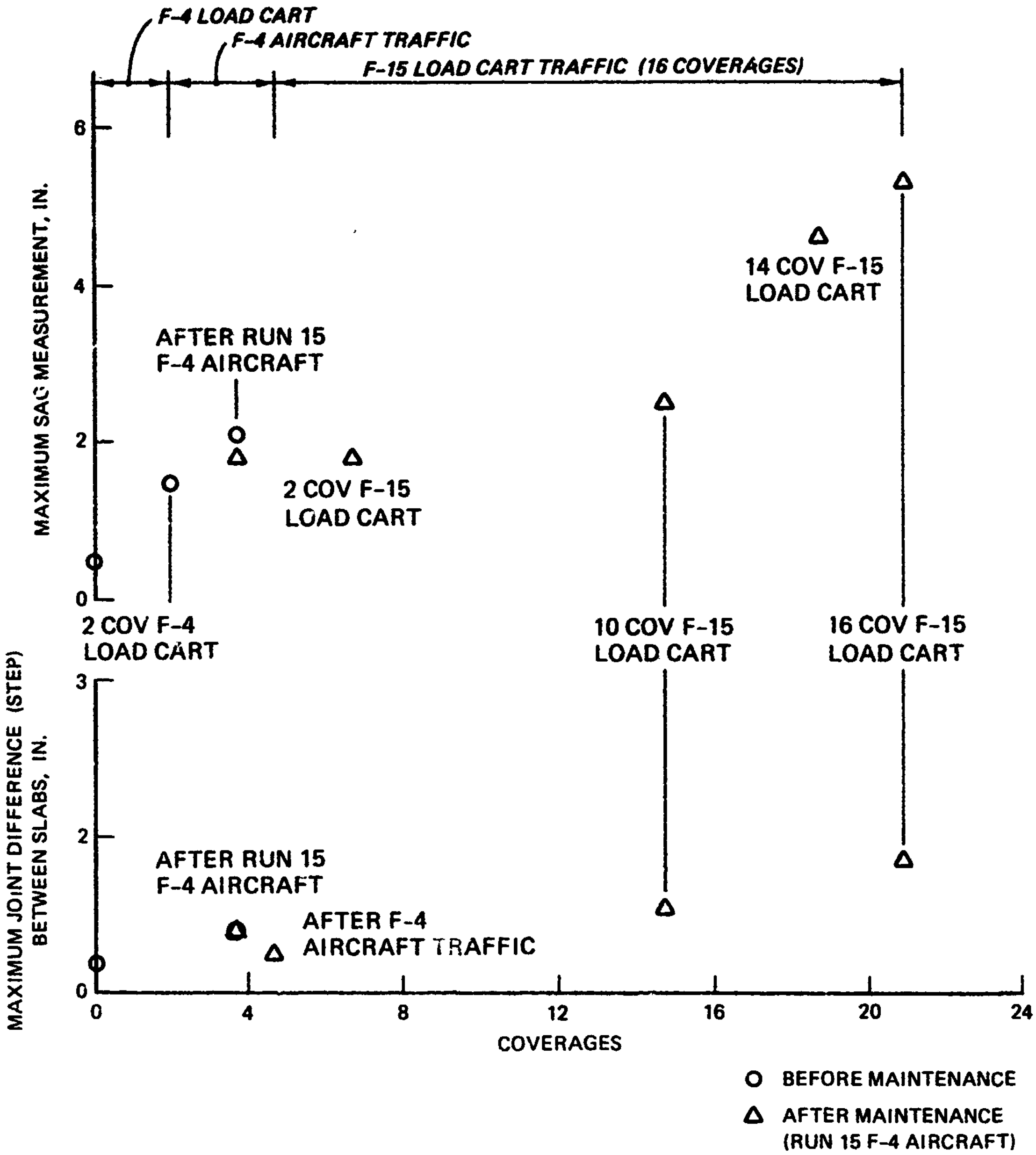


Figure 37. Maximum sag measurements and maximum joint difference (step) between the slabs for the north side of the crater repair (F-15 traffic lane)

shows the defects and their locations after 16 coverages.

24. After the F-15 load cart traffic, F-4 load cart traffic was applied to the south part of the crater repair (Figure 13). The proof-testing of the crater repair with the F-4 load cart was considered equivalent to two coverages. These are included in the coverage count. Photo 35 shows the traffic lane before traffic was resumed. A 1.82-in. sag measurement was recorded. After six coverages, the sag measurement had increased to 3.75-in. and

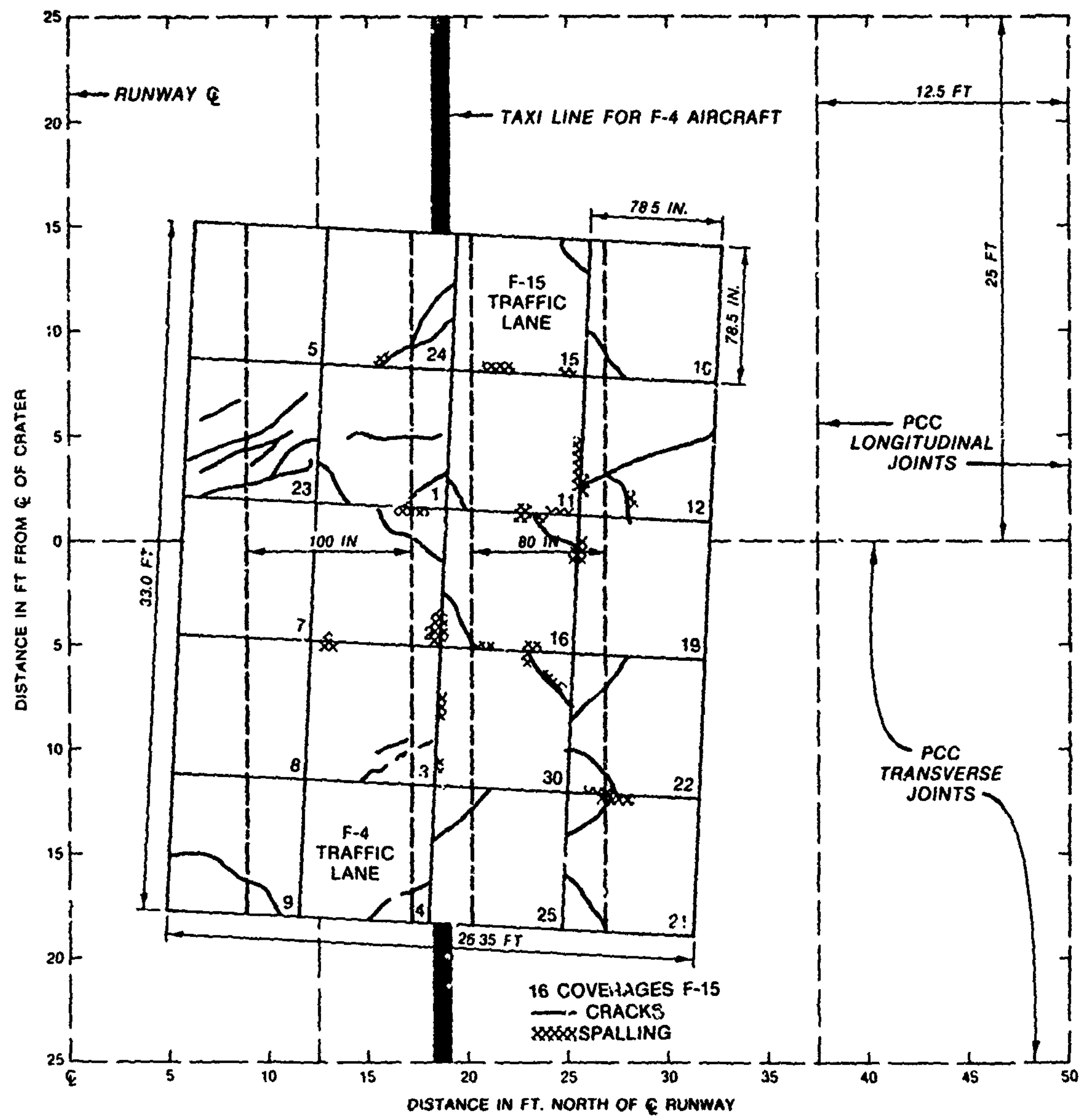


Figure 38. Defects in slabs after 16 coverages of F-15 traffic

spalling of the PCC was noted (Figure 39). Photo 36 shows the traffic lane after 10 coverages. The spalling that is visible is located on slabs 7, 8, and 3 (Figure 40). The maximum sag measurement was 4.38 in. As traffic continued to 20 coverages, the sag measurement decreased to 4.00 in. Figures 41 through 46 compare profile data at 20 coverages of F-4 traffic with 16 coverages of F-15 traffic (conditions before F-4 traffic was resumed). Figure 47 shows the location of the spalling in the slabs. Photo 37 is a general view of the traffic lane after 20 coverages. At that time, the angle iron band on slab 8 was starting to work loose and the 6-in. PCC (runway, not repair) on the east edge of the crater repair was starting to break up. At

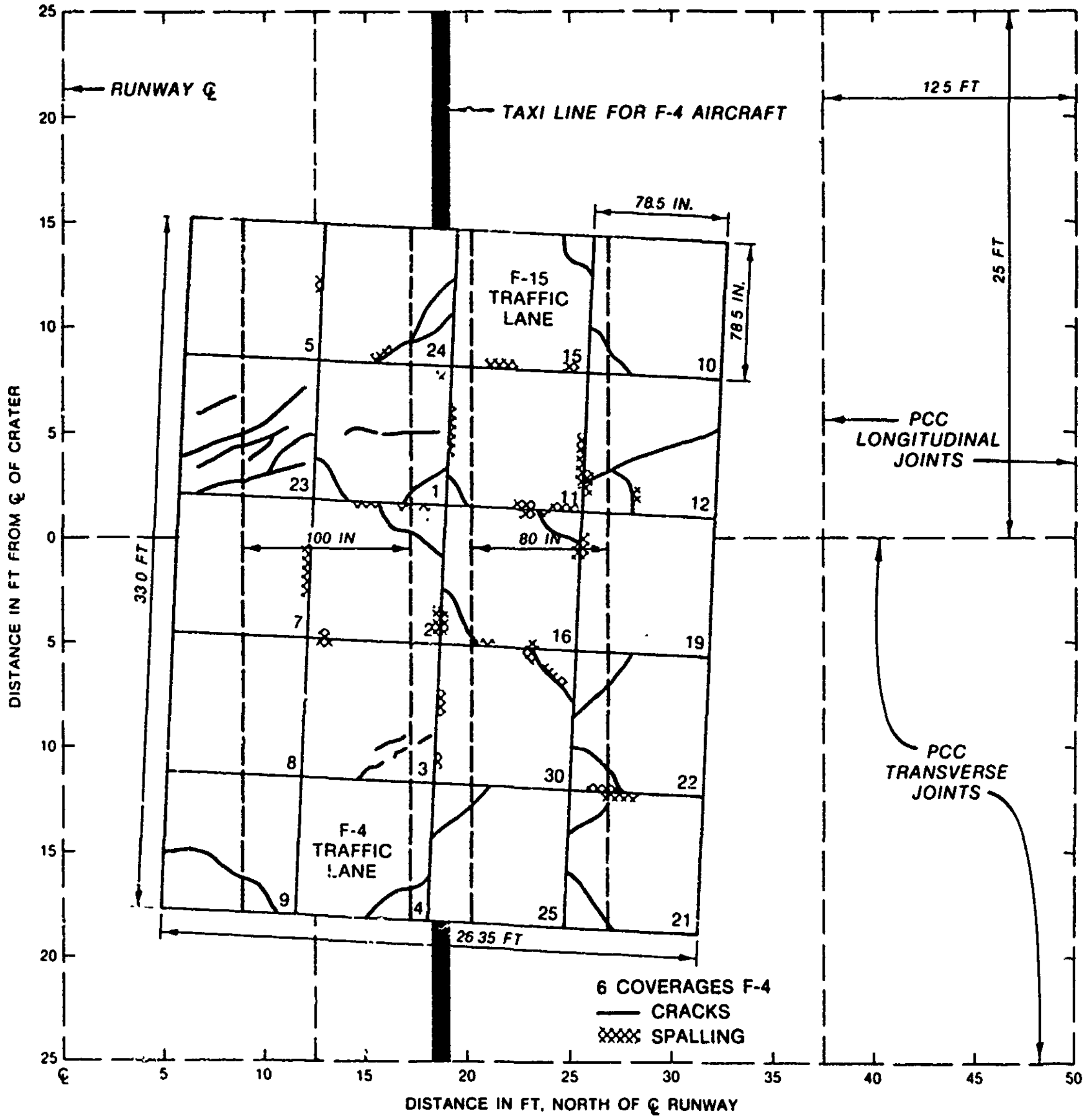


Figure 39. Defects in slabs after 6 coverages of F-4 traffic

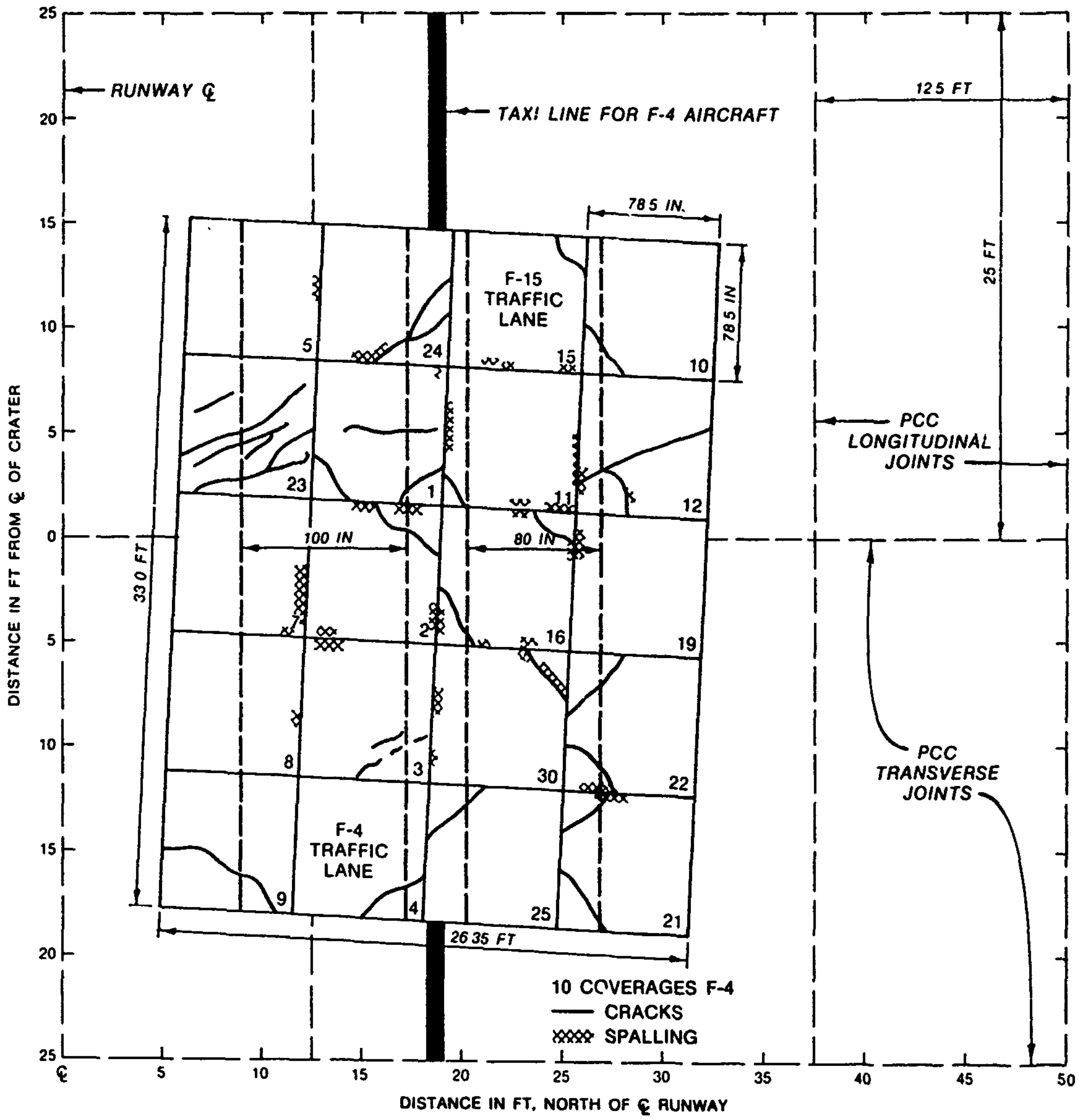


Figure 40. Defects in slabs after 10 coverages of F-4 traffic

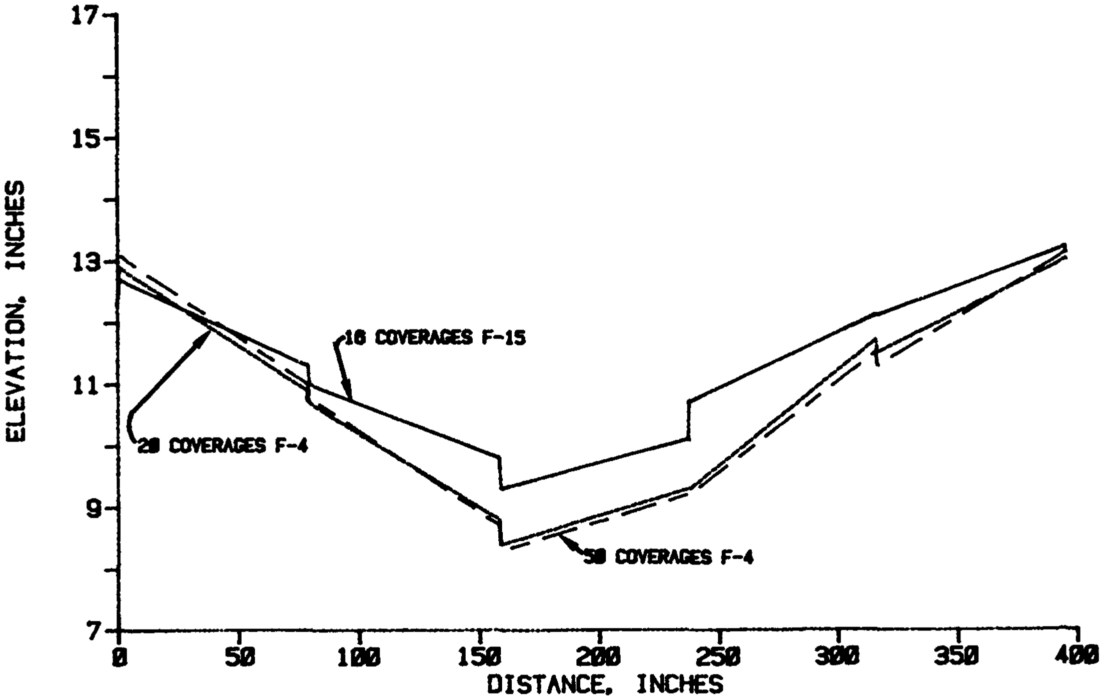


Figure 41. Line 7, profile, precast slab repair after F-4 traffic

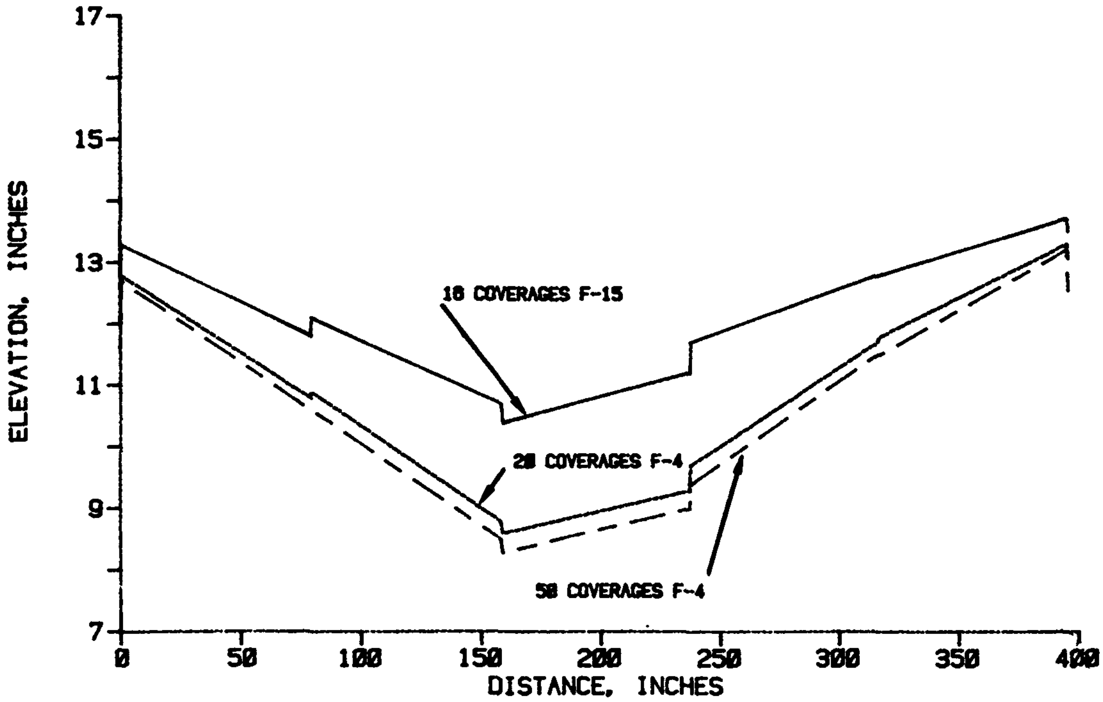


Figure 42. Line 8, profile, precast slab repair after F-4 traffic

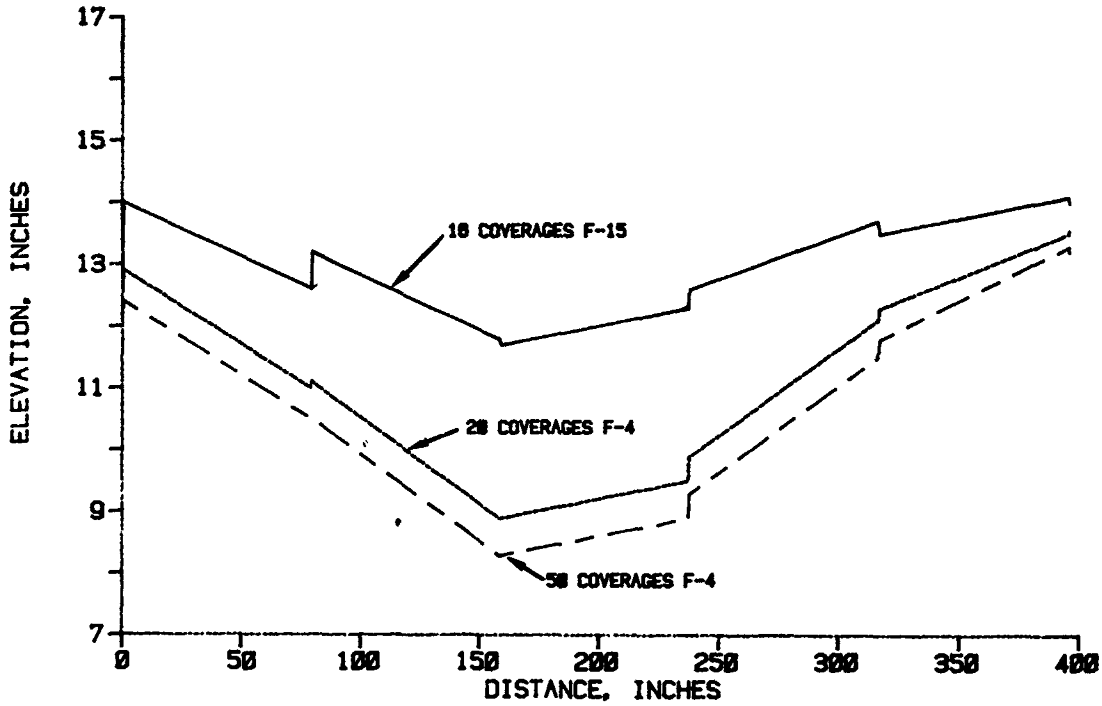


Figure 43. Line 9, profile, precast slab repair after F-4 traffic

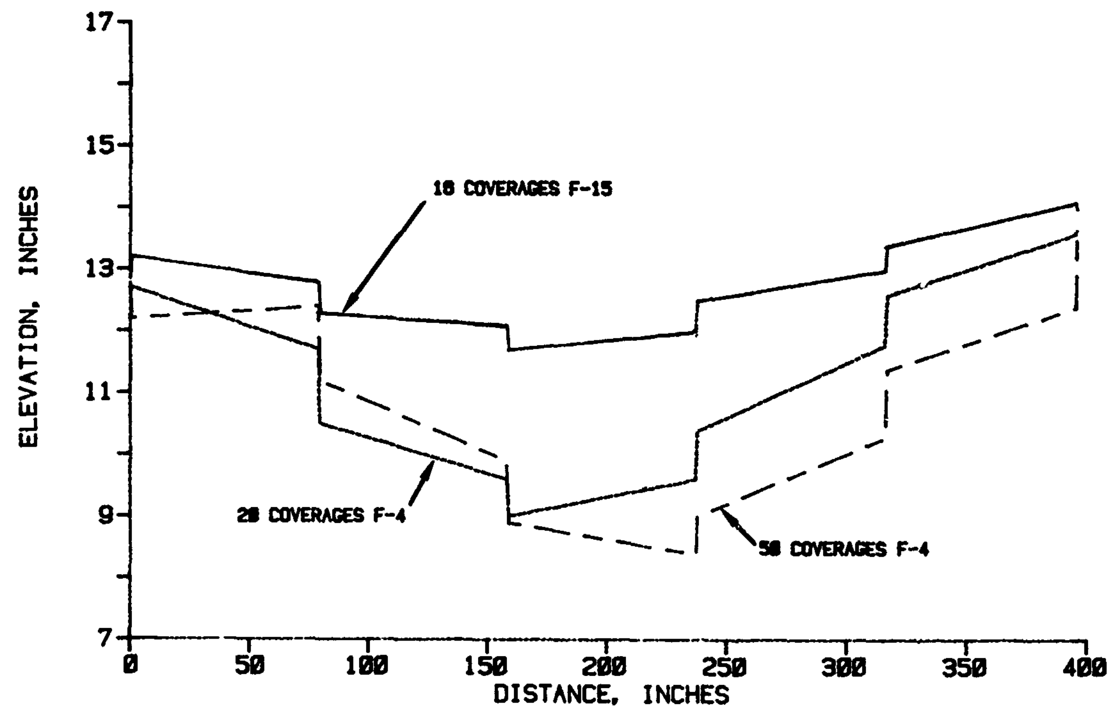


Figure 44. Line 10, profile, precast slab repair after F-4 traffic

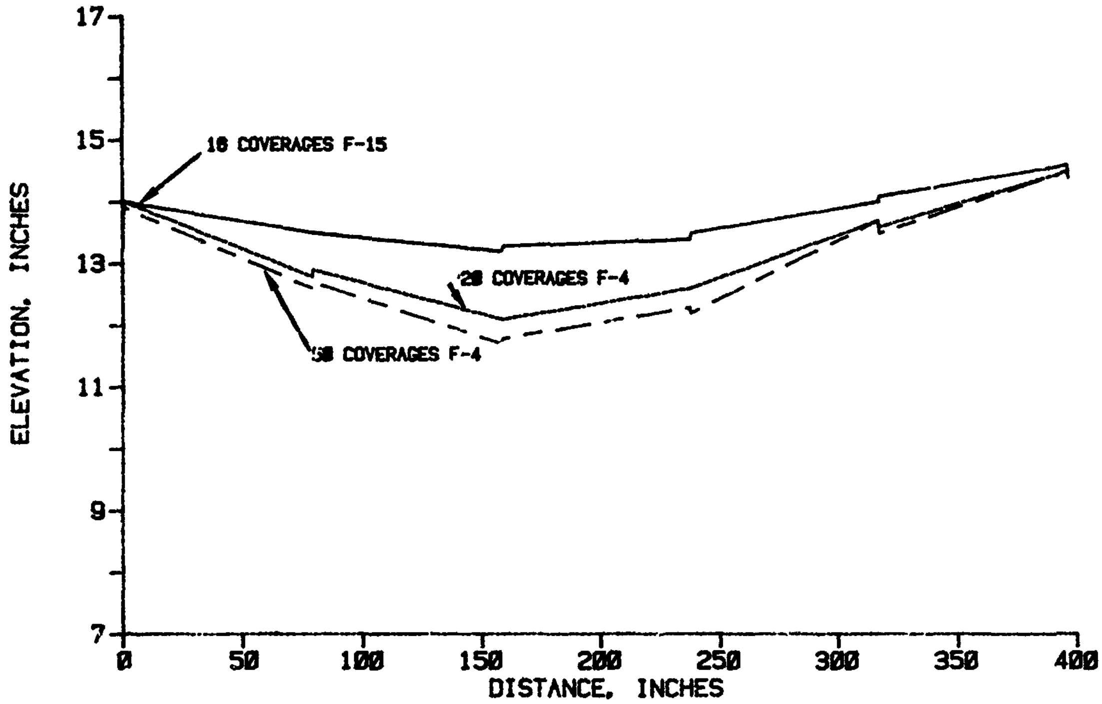


Figure 45. Line 11, profile, precast slab repair after F-4 traffic

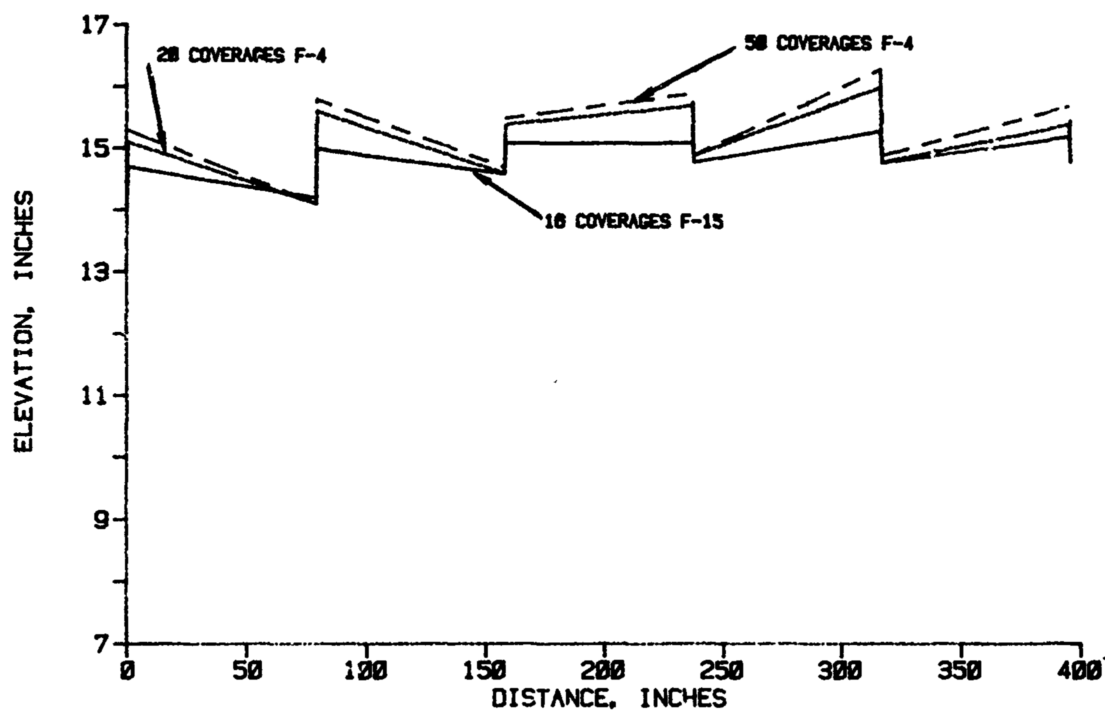


Figure 46. Line 12, profile, precast slab repair after F-4 traffic

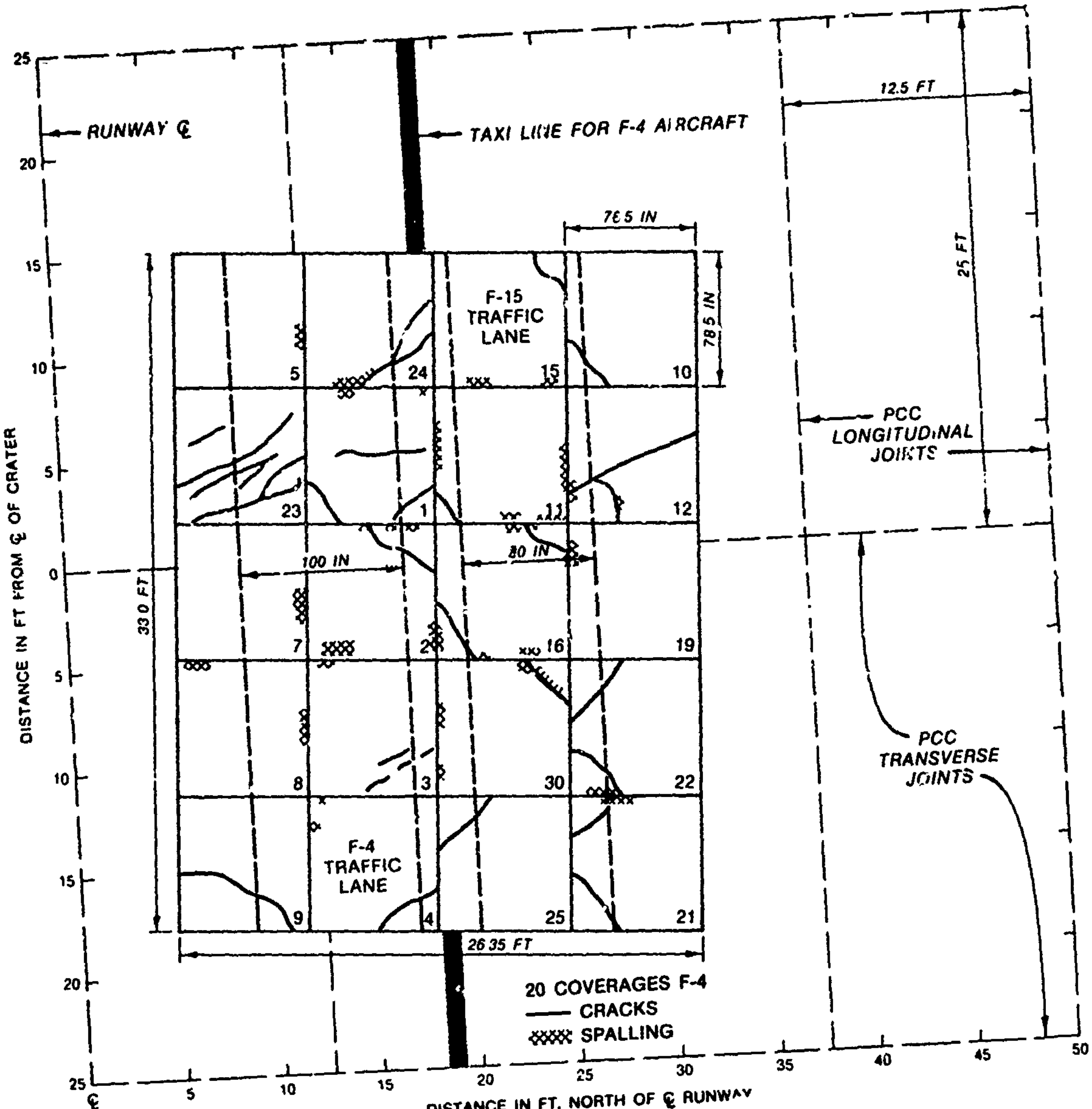


Figure 47. Defects in slabs after 20 coverages of F-4 traffic

24 coverages, the sag measurement increased to 4.50 in. and remained 4.50 in. through 36 coverages (Table 4). Photo 38 shows the surface condition of the repair after 30 coverages; spalling is evident in this photo. Cracks were also evident in the 6-in. PCC original runway pavement at this time. Traffic was stopped after 50 coverages when the sag measurement was 5.00 in. The maximum sag measurements and the maximum joint difference (step) between the slabs recorded during all phases of traffic applied on the south side of the crater repair (F-4 traffic lane) and plotted are shown in Figure 48. Photo 39 is a general view of the traffic lane after 50 coverages. Spalled areas are visible on slabs 8 (note loose angle iron), 3, and 5 and there was spalling of

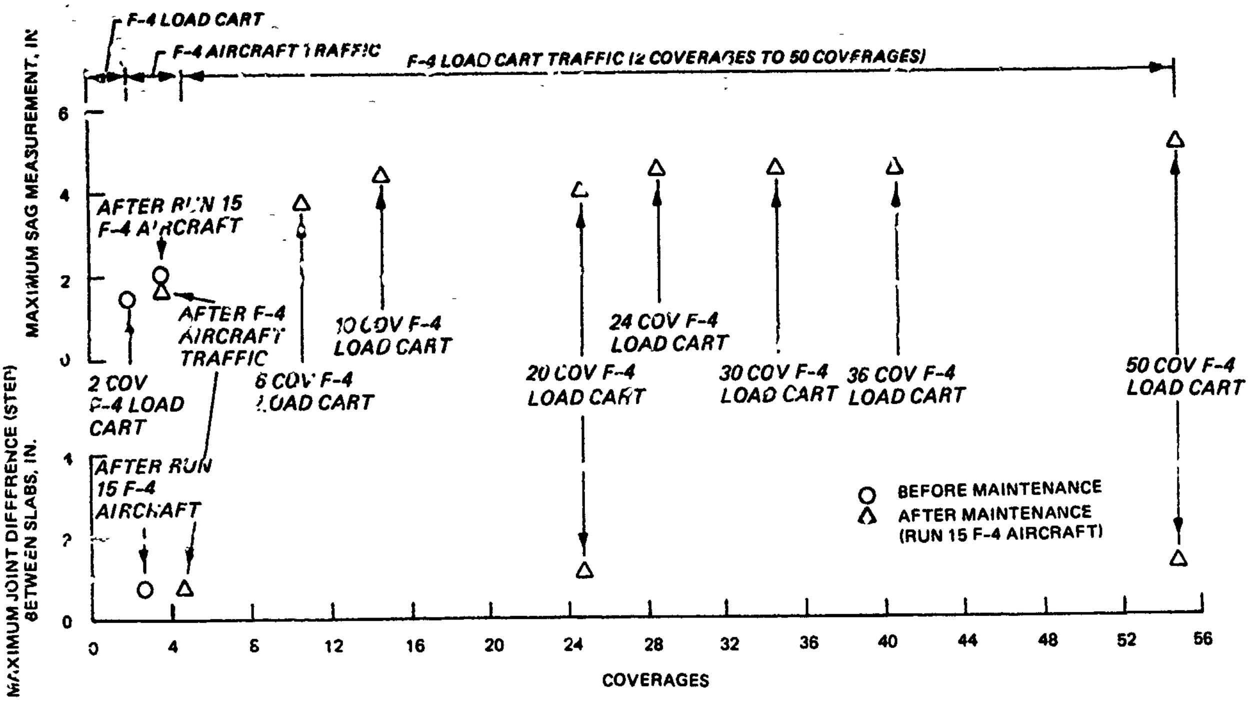


Figure 48. Maximum sag measurements and maximum joint difference (step) between the slabs for the south side of the crater repair (F-4 traffic lane)

the cracks in the original PCC east of the crater repair. Figure 49 shows the location of all the spalling in the crater repair. There were no breaks or cracks generated in any of the slabs by F-4 load cart traffic. Figures 41 through 46 show profile data (50 coverages) in comparison with data when F-4 load cart traffic was resumed and after 20 coverages.

25. After traffic the slabs were removed using a military all-terrain forklift and chain hoist with the lifting keys attached. The slab removal was initiated in the northwest corner of the repair. The slabs were removed with a very minimum effort. Photo 40 shows the repair with the slabs removed. It is evident that there were voids between the slabs and leveling course because a live frog was found under the slabs when they were removed and the voids are reflected in the final profile data. Figures 50 through 61 show profile data giving comparisons of 0-coverage data (before any traffic), 50-coverage F-4 data (after all traffic had been applied), and the surface of the leveling course (slab removed).

26. Surface roughness measurements taken after the slabs were removed are shown in Table 4. These measurements are the vertical distances measured from a string across the repair which was on the surface of the original 6-in. PCC to the surface of the leveling course. Table 1 shows data taken after

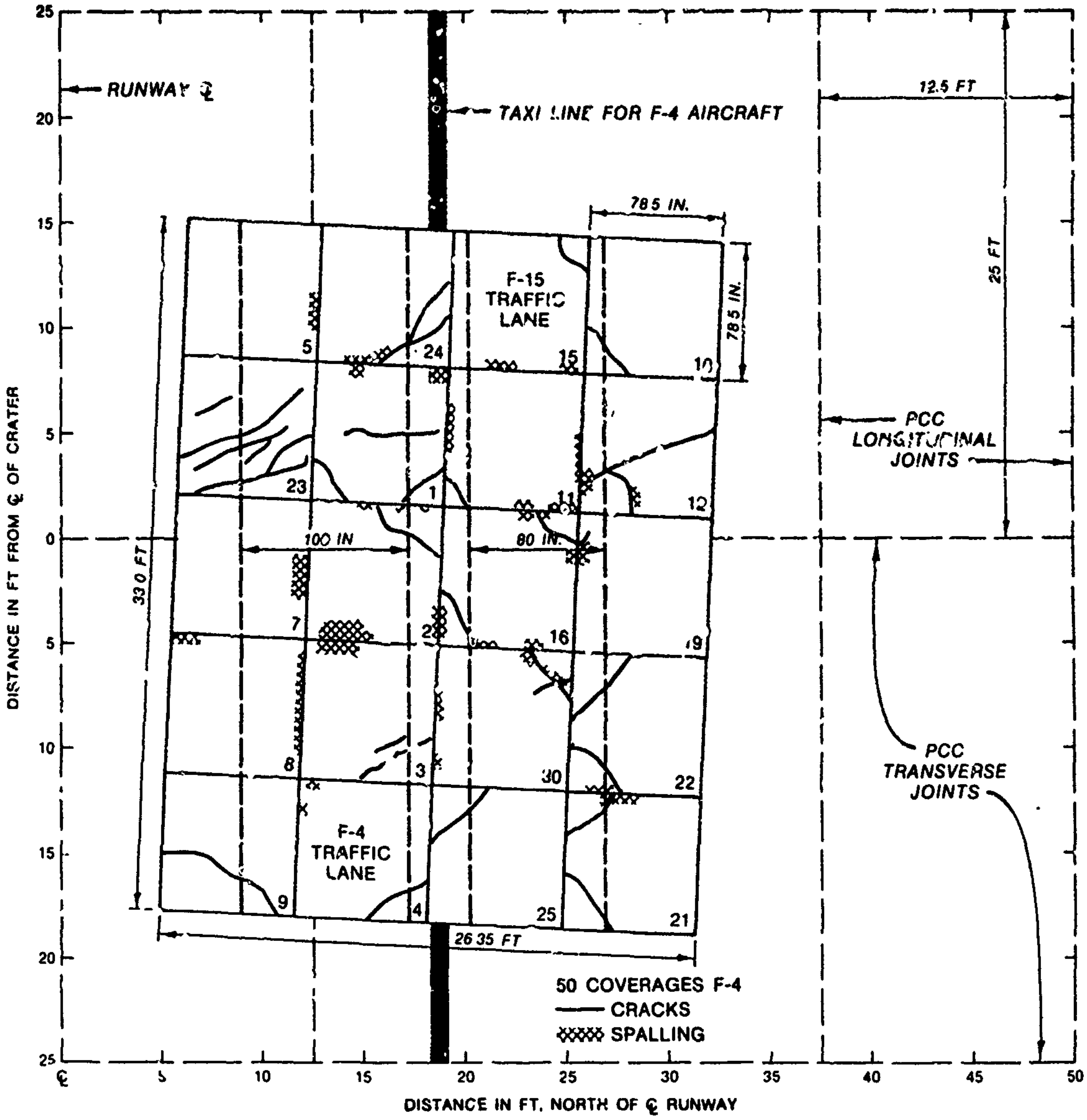


Figure 49. Defects in slabs after 50 coverages of F-4 traffic

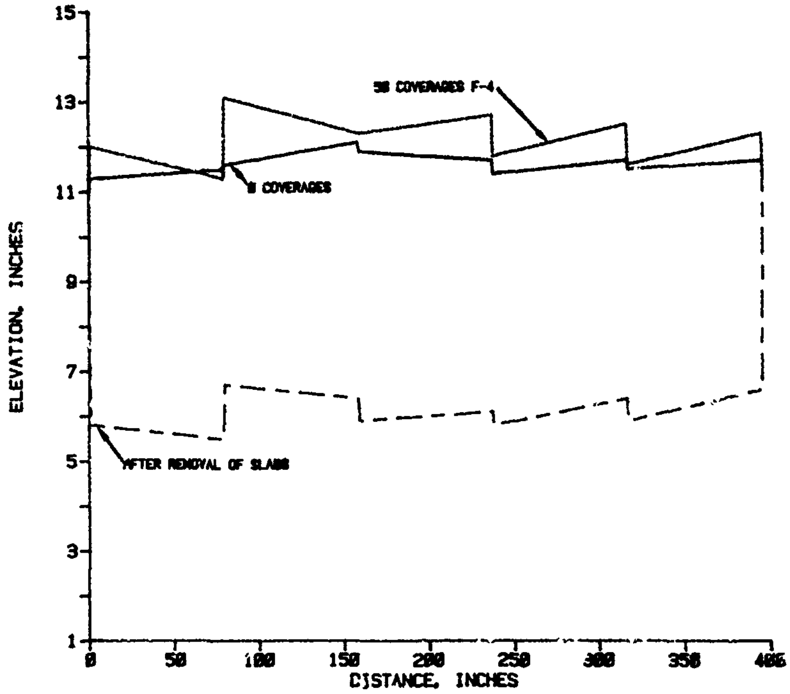


Figure 50. Line 1, profile, precast slab repair, 0 coverages, after all traffic and after slab removal

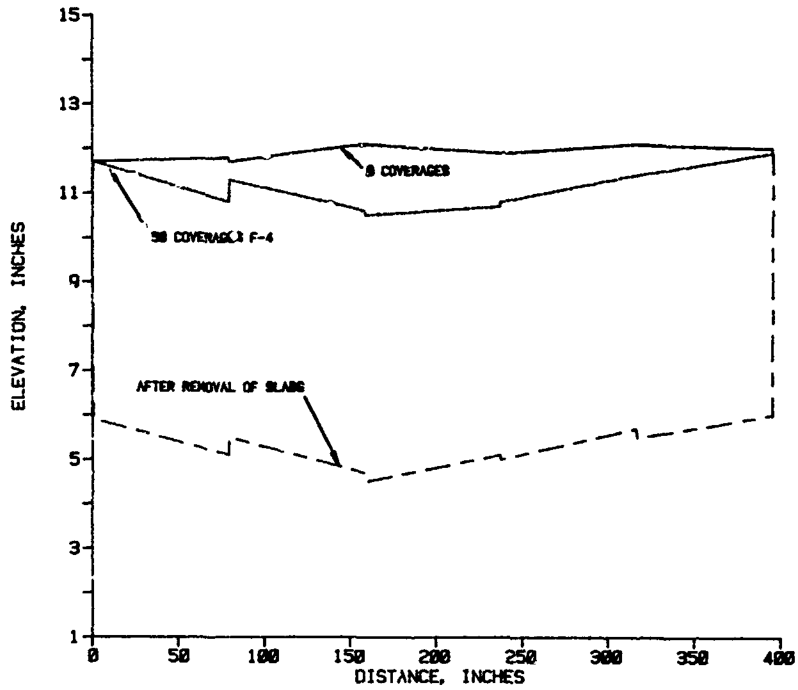


Figure 51. Line 2, profile, precast slab repair, 0 coverages, after all traffic and after slab removal

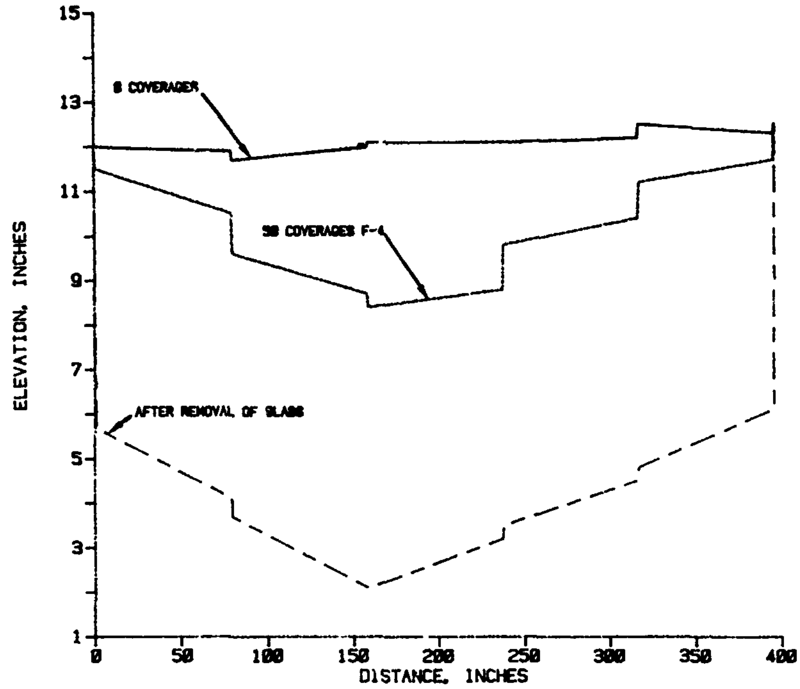


Figure 52. Line 3, profile, precast slab repair, 0 coverages, after all traffic and after slab removal

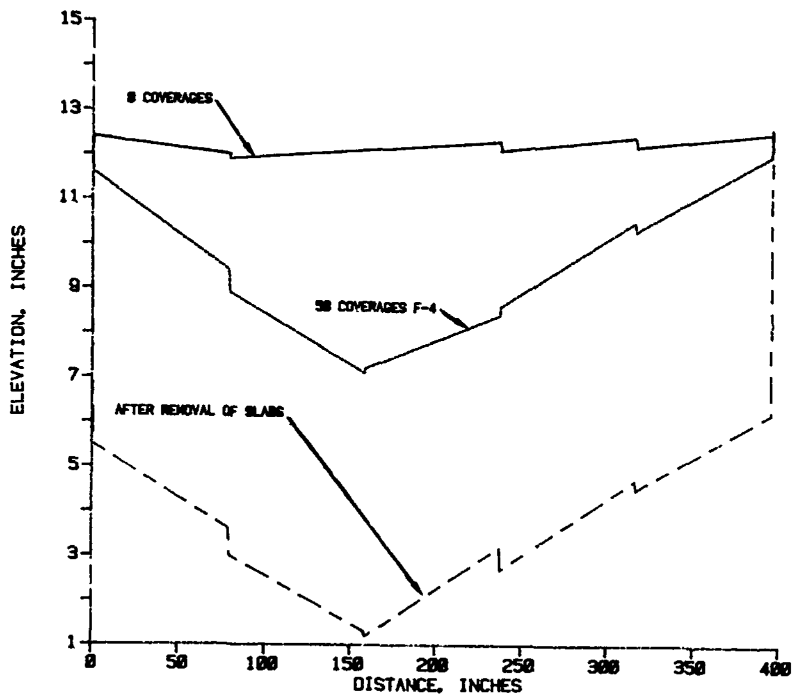


Figure 53. Line 4, profile, precast slab repair, 0 coverages, after all traffic and after slab removal

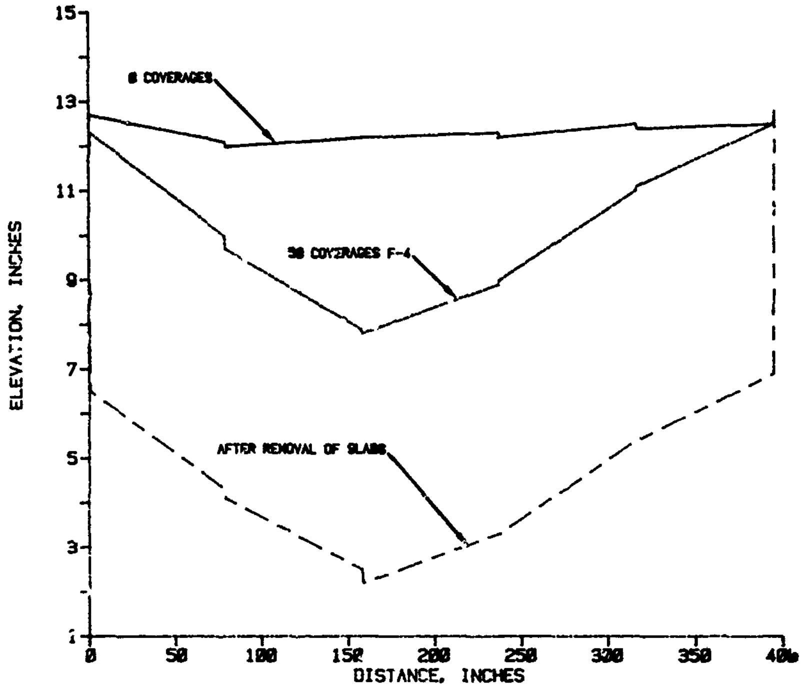


Figure 54. Line 5, profile, precast slab repair, 0 coverages, after all traffic and after slab removal

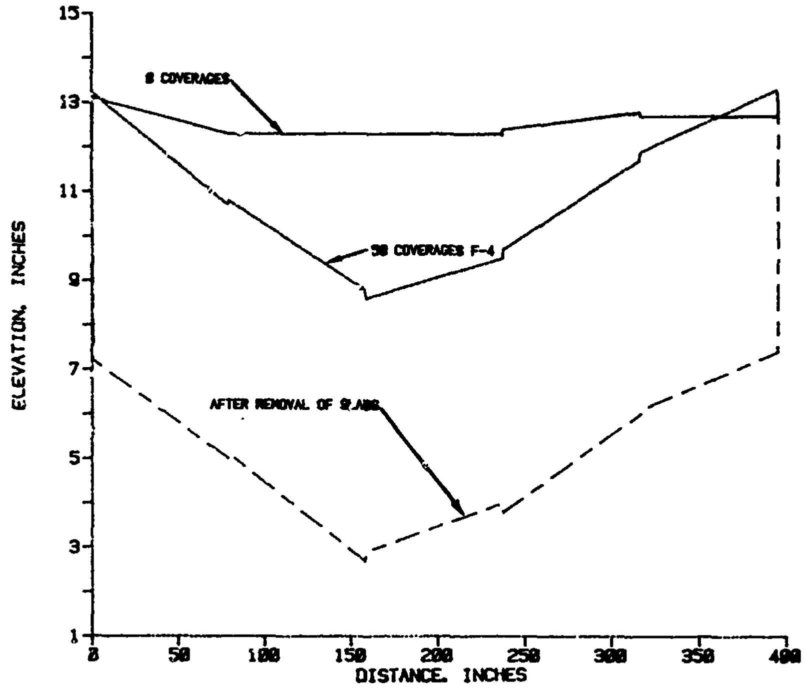


Figure 55. Line 6, profile, precast slab repair, 0 coverages, after all traffic and after slab removal

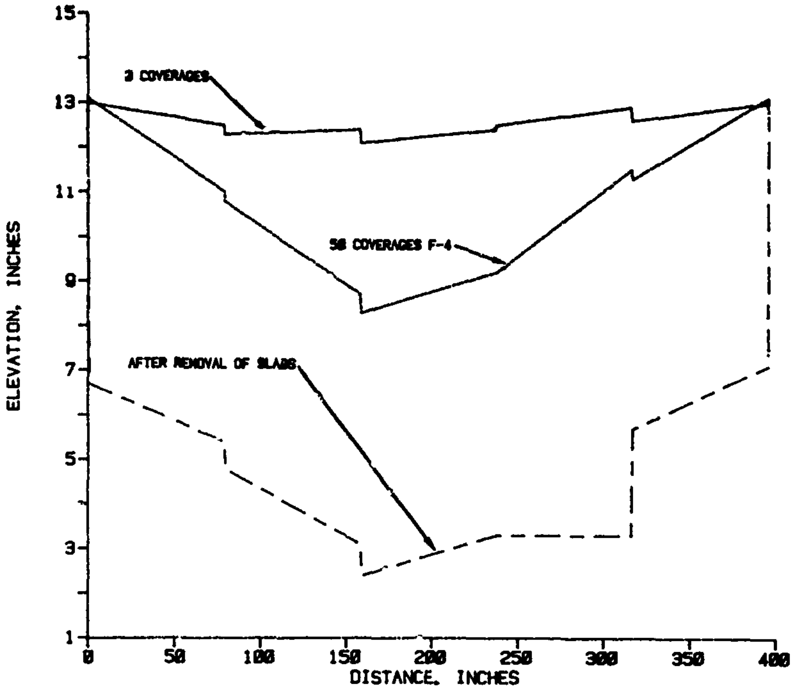


Figure 56. Line 7, profile, precast slab repair, 0 coverages, after all traffic and after slab removal

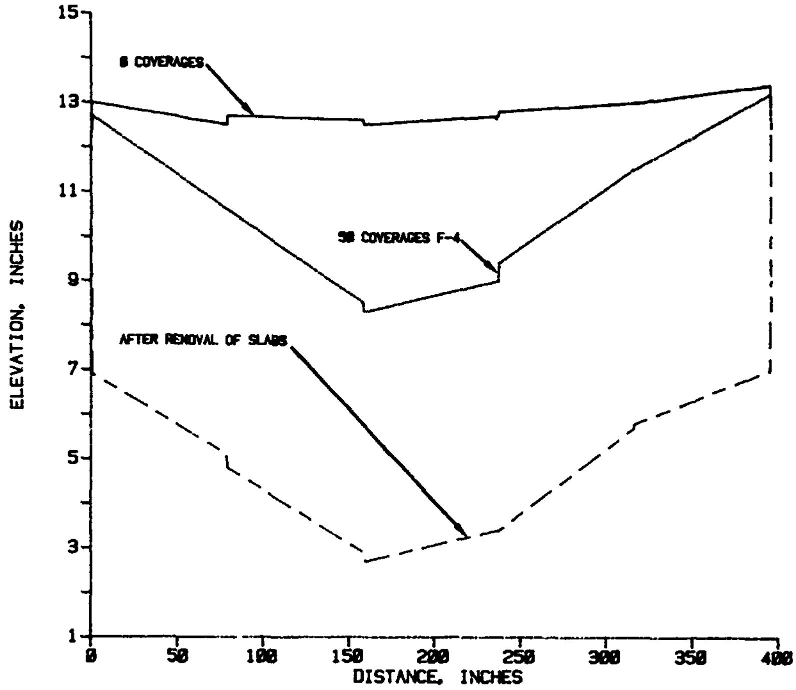


Figure 57. Line 8, profile, precast slab repair, 0 coverages, after all traffic and after slab removal

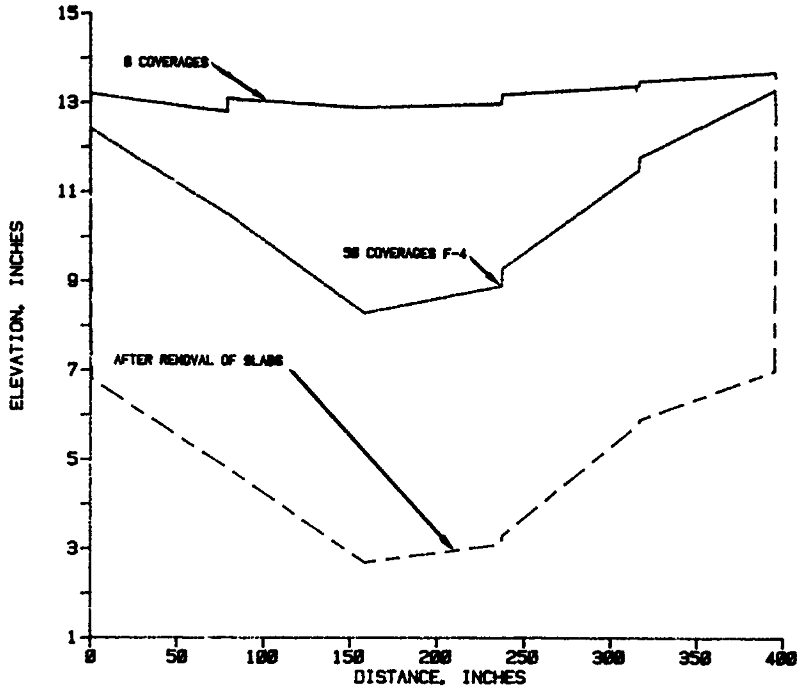


Figure 58. Line 9, profile, precast slab repair, 0 coverages, after all traffic and after slab removal

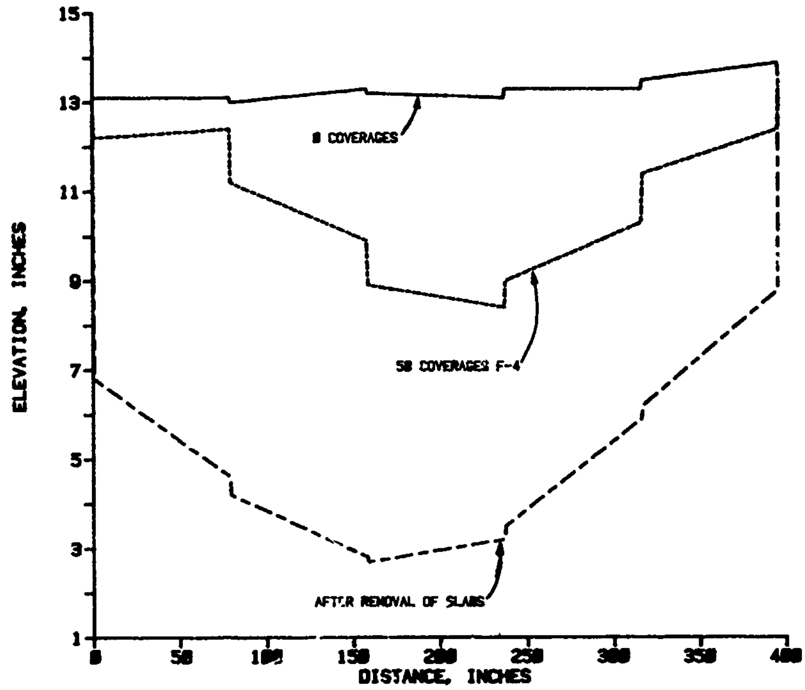


Figure 59. Line 10, profile, precast slab repair, 0 coverages, after all traffic and after slab removal

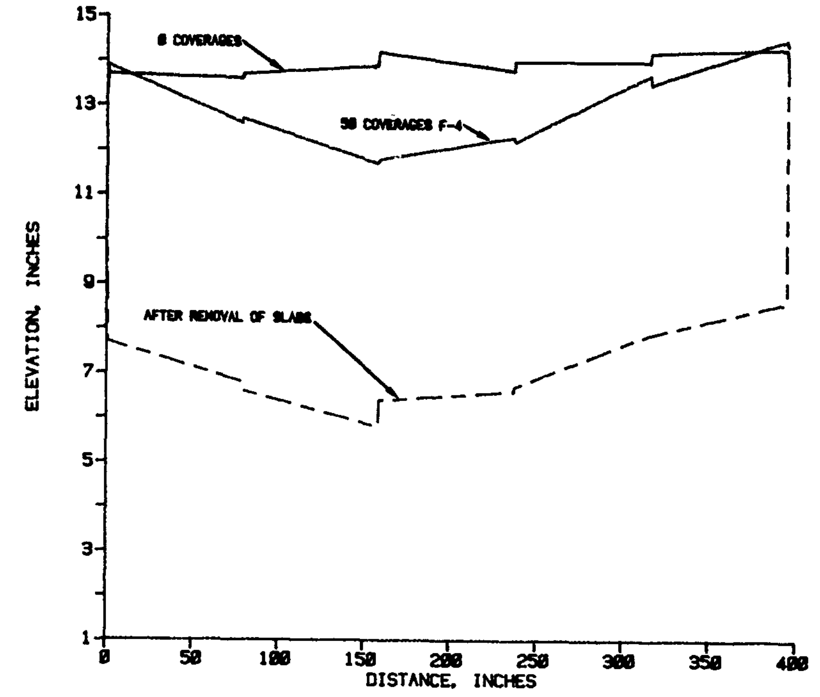


Figure 60. Line 11, profile, precast slab repair, 0 coverages, after all traffic and after slab removal

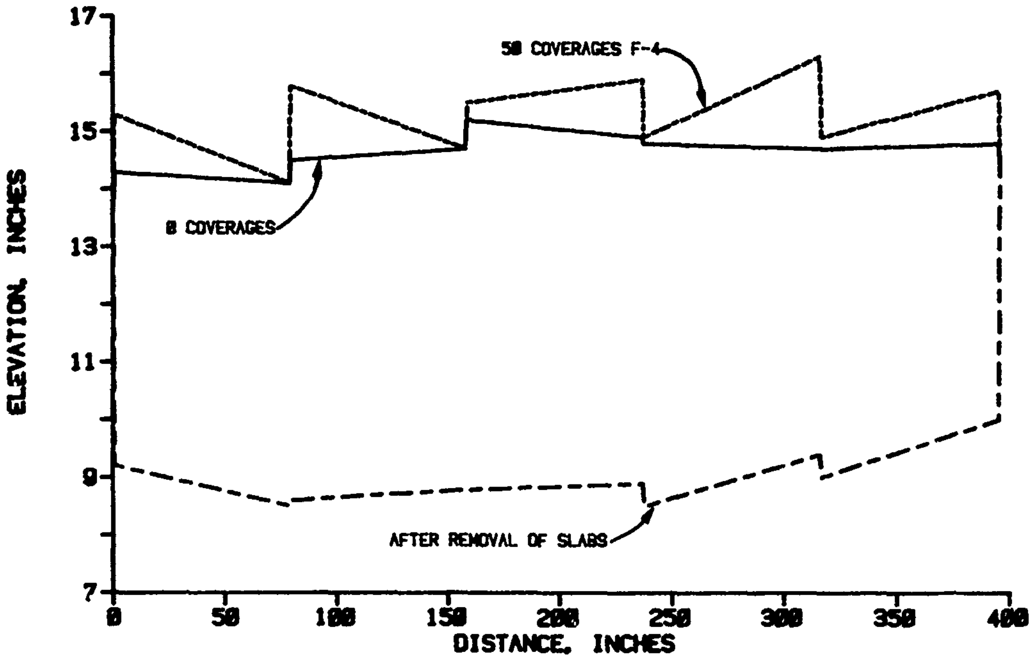


Figure 61. Line 12, profile, precast slab repair, 0 coverages, after all traffic and after slab removal

traffic which includes modulus of subgrade reaction, k ; density; and moisture determinations taken on the leveling course and the moisture and density subgrade (silty sand). The modulus of subgrade reaction, k , of the leveling course increased from 88 pci before traffic to 368 pci after traffic and the density of this material increased 10.1 pcf. After the leveling course and ballast rock were removed, water was observed standing in the "original" crater due to rain during traffic. Figure 62 shows the amount of rainfall recorded at a weather station located approximately 19 miles from NAA during the construction and trafficking of the crater repairs. A total of 3.28 in. was recorded during the construction and traffic period. This amount could vary slightly from the amount received at NAA due to local thundershowers.

27. Figure 63 shows profile data taken from the center of the crater repair out 500 ft east. The profile data was taken before any traffic was applied to the center and was located along the south wheel path of the F-4 aircraft.

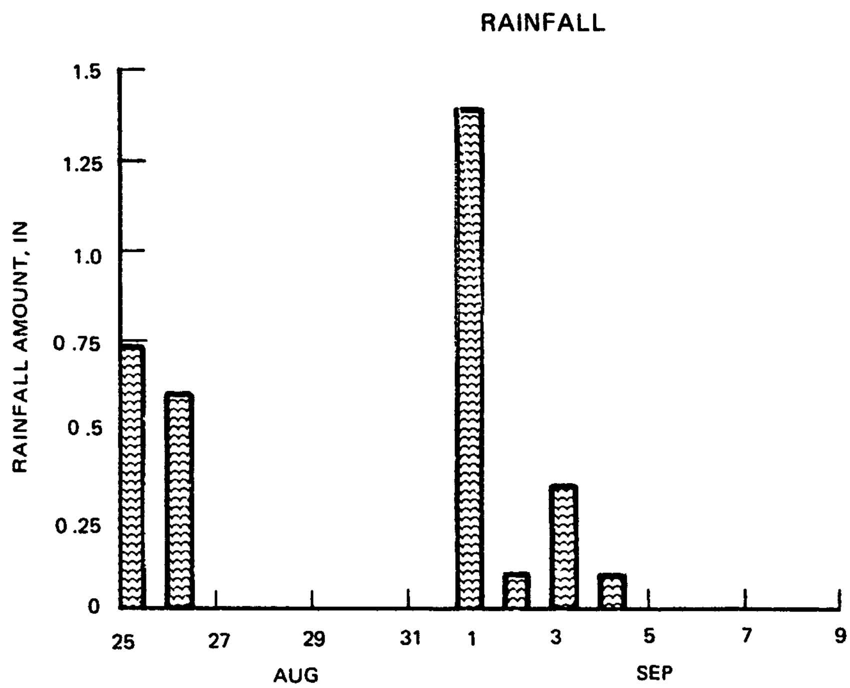


Figure 62. Rainfall during the construction and trafficking of the crater repairs

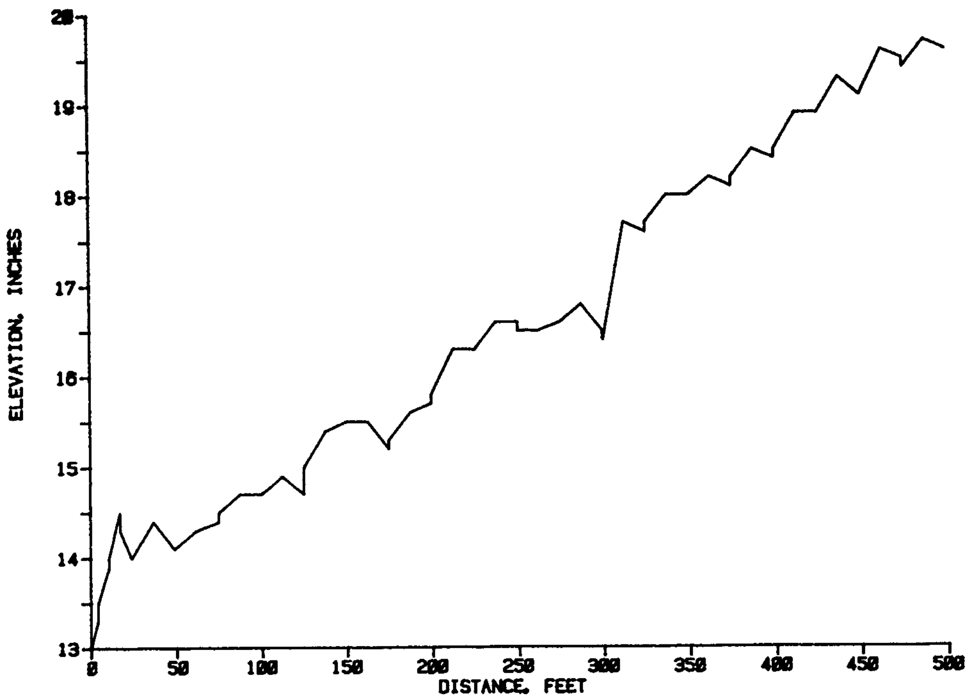


Figure 63. 500-ft lead-in profile, from the center of the crater east, south wheel path F-4 aircraft, precast slab repair

Summary of Findings

28. The findings from the traffic testing of the precast slab repair show that:

a. Early F-4 traffic (proof-testing and aircraft) and the F-15 traffic generated cracks and/or breaks in the slabs but these cracks and/or breaks did not impair the performance of the crater repair.

b. Both the F-4 and F-15 load cart traffic produced spalling that would likely have been a FOD problem.

c. The initial movement (tipping) of the slabs indicate that a better seating method or some degree of compaction might be desirable before subjecting a crater repair of this design (Figures 4 and 5) to aircraft traffic. The proof-testing reduced the movement or tipping by one-half or more, indicating a need for compaction.

d. The traffic by the F-4 load cart also indicated that some type or compaction might be desirable. The sag measurement at 2 coverages was 1.81 in. and after 24 coverages, 4.5 in., an increase of 2.69 in. However, the repair stabilized at this time and 26 additional coverages were applied with a sag increase of only 0.50 in.

e. Figures 64 and 65 show the F-15 and F-4 traffic distribution with respect to slab edges. On the F-4 traffic lane, the edges (joint line) are affected by at least three lines of the 100 percent traffic and the F-4 by only one line. This could be the reason for the greater sag measurement under initial F-4 traffic.

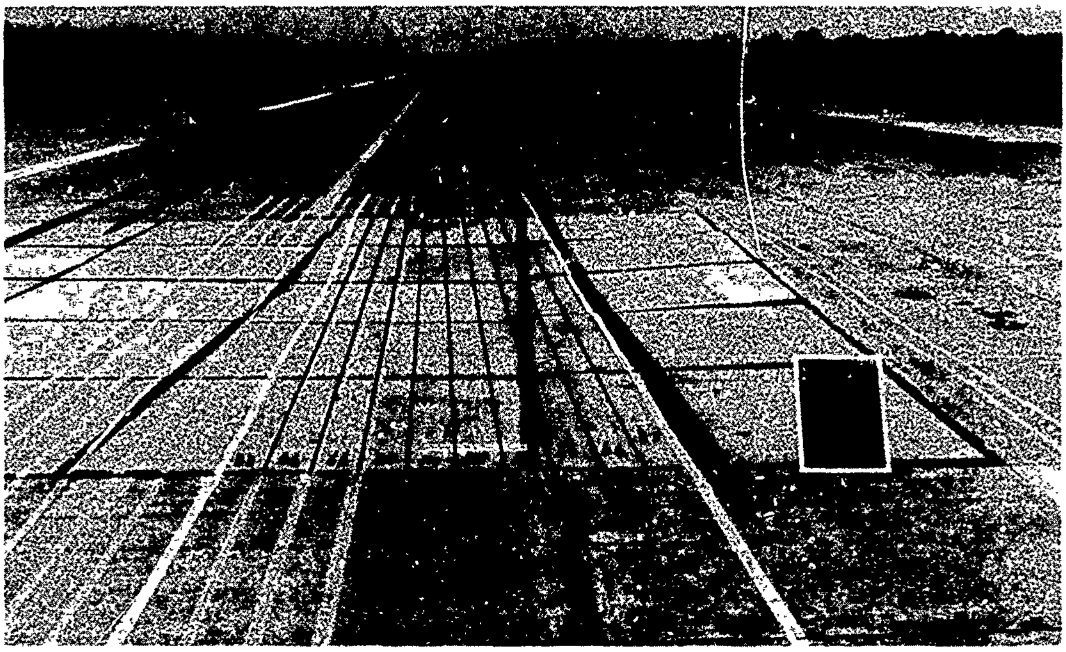


Figure 64. Location of F-15 traffic distribution with respect to slab edges

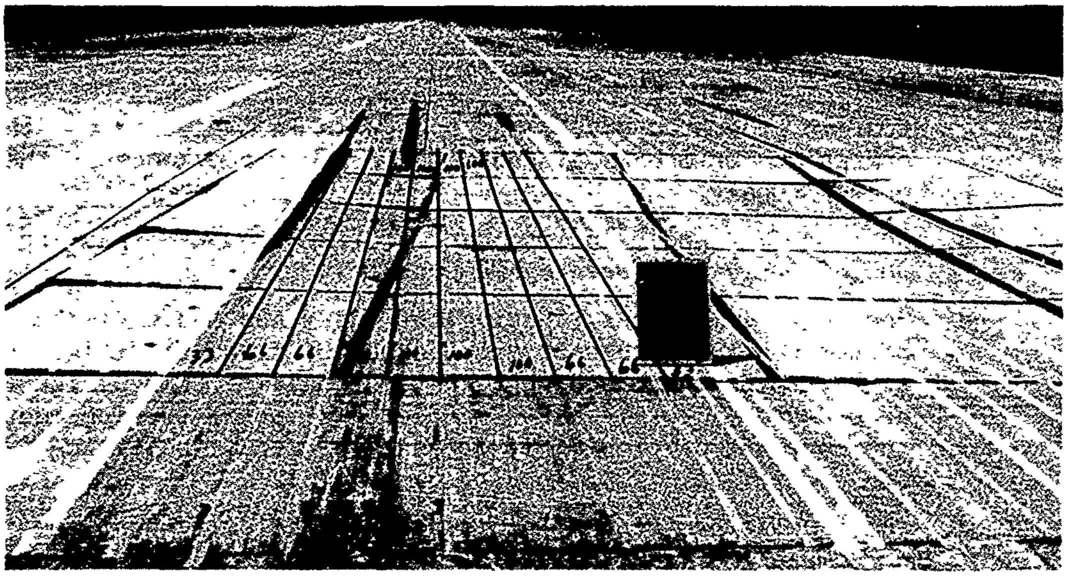


Figure 65. Location of F-4 traffic distribution with respect to slab edges

f. The F-4 aircraft bounced and had a side-to-side rocking motion at the 20- to 30-knot taxi speeds; however, the pilot did not consider this a major problem. The pilot did not express concern for roughness at speeds slower or faster than 20 to 30 knots; sag was not a problem and the pilot could not distinguish any difference on touch-and-go operations on the slab repair versus permanent pavements.

PART IV: TESTING AND BEHAVIOR UNDER TRAFFIC-- FOD COVER REPAIR (EAST CRATER)

Sequence of Test Traffic

29. The sequence of test traffic applied to the east crater repair (FOD cover) was as follows: (a) proof-testing the entire width of the repair with the F-4 test cart, (b) F-4 aircraft operations, (c) F-15 test cart traffic, and (d) F-4 test cart traffic. During the traffic test period, visual observations, level readings, and sag measurements were recorded. These data were supplemented by photographs. In-place CBR, moisture content, and density determinations were conducted on the pavement layers during and after traffic and are presented in Table 2. The performance of this crater repair and test data recorded during traffic testing are discussed in the following paragraphs.

FOD Cover Repair

30. A layout of the crater repair is shown in Figure 66. Surface roughness measurements recorded before traffic as shown in Table 6 indicate a 2.5- to 3.0-in. upheaval and a 0.5- to 1.0-in. sag in the surface of the crater repair. These measurements were recorded in the wheel (gear) paths of the F-4 aircraft. Three profiles (in the direction of traffic), one in each wheel (gear) path, were measured and the results are plotted in Figures 67 through 69. Figures 70 through 72 show cross-section data (transverse to traffic) at the west quarter point, center, and east quarter points of the crater, respectively. After placement of the FOD cover, the crater repair was proof rolled before F-4 aircraft traffic. Proof rolling was accomplished by applying two coverages of F-4 load cart traffic over the entire crater repair area. The load cart proof loading was started on the south side of the crater repair and approximately one tire print width outside the edge of the crater. The load cart was driven forward and backward in the same path and then shifted north one wheel path (10 in.) and the load cart was again driven forward and backward. This rolling pattern, which resulted in two coverages of the F-4 load cart, was repeated until the entire width of the crater repair had been rolled. A slight bow wave was noticed in the FOD cover when the load

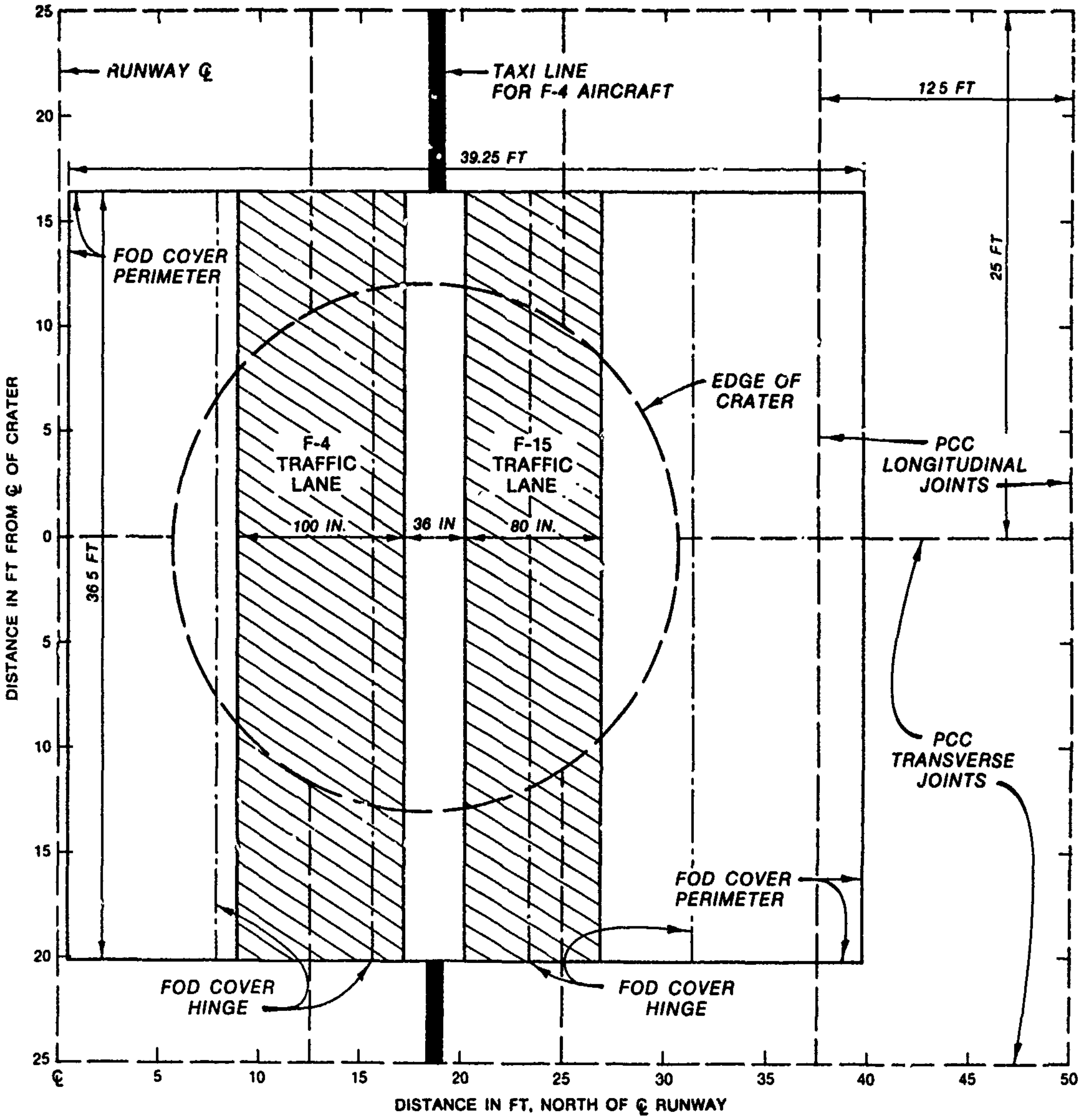


Figure 66. Layout of FOD cover repair

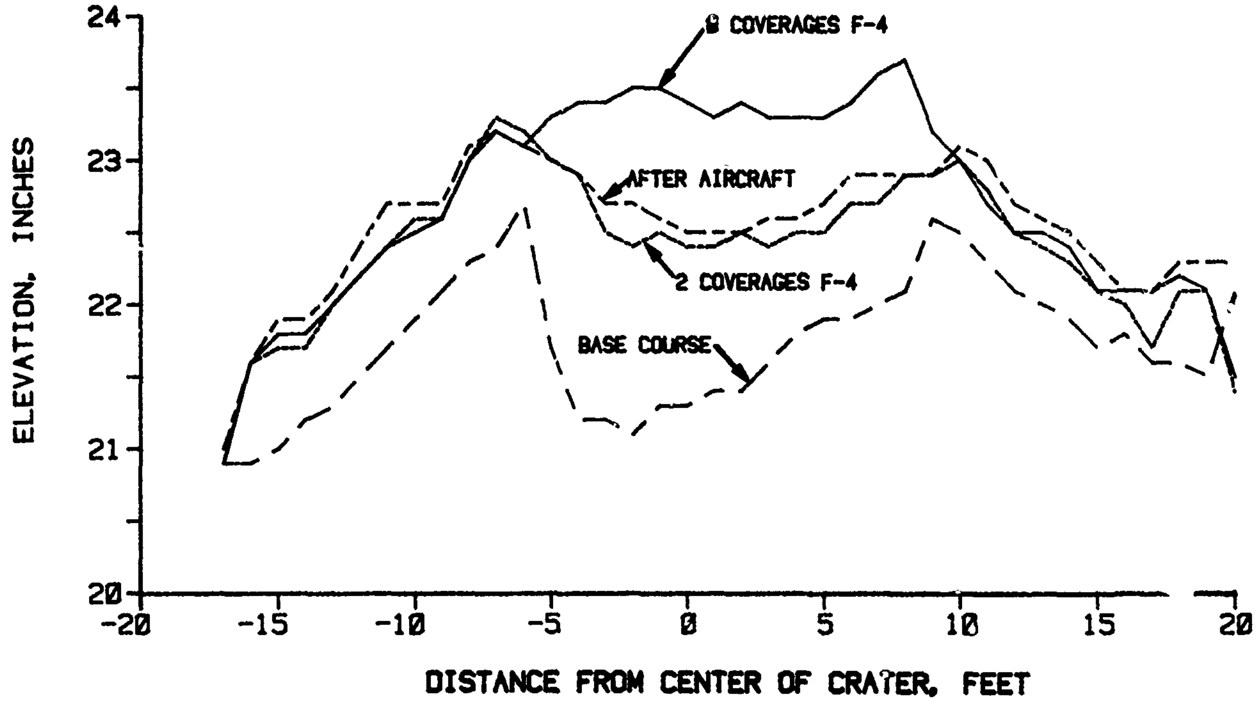


Figure 67. North wheel path profile, FOD cover repair, 0 coverages, 2 coverages of F-4 load cart, and after F-4 aircraft traffic

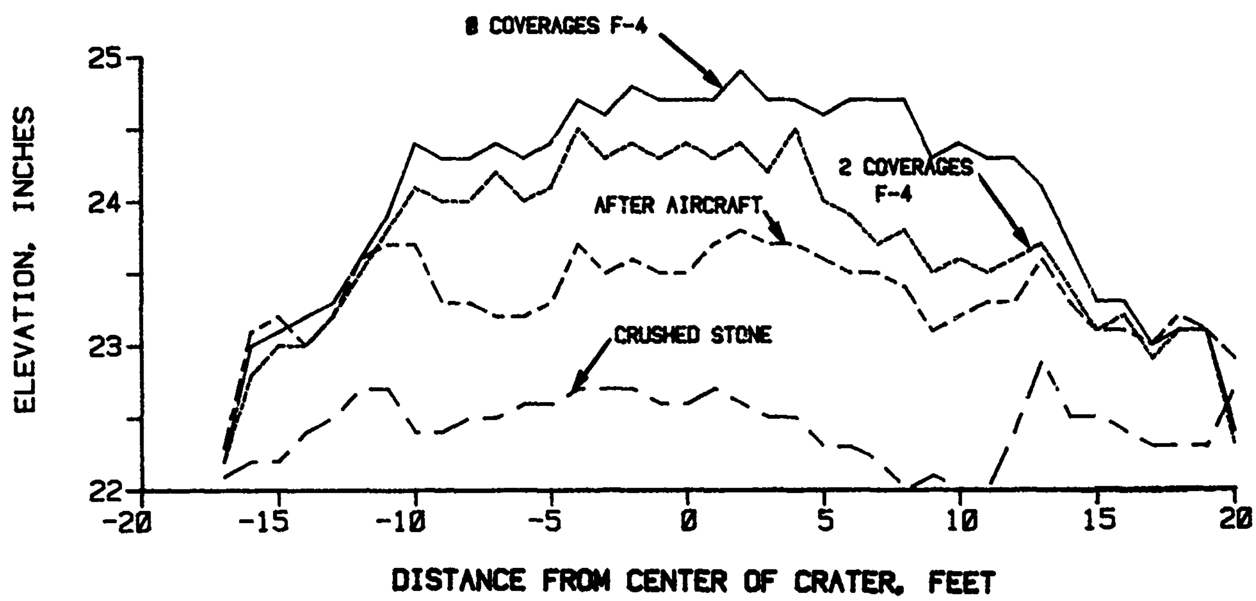


Figure 68. Center profile, FOD cover repair, 0 coverages, 2 coverages of F-4 load cart, and after F-4 aircraft traffic

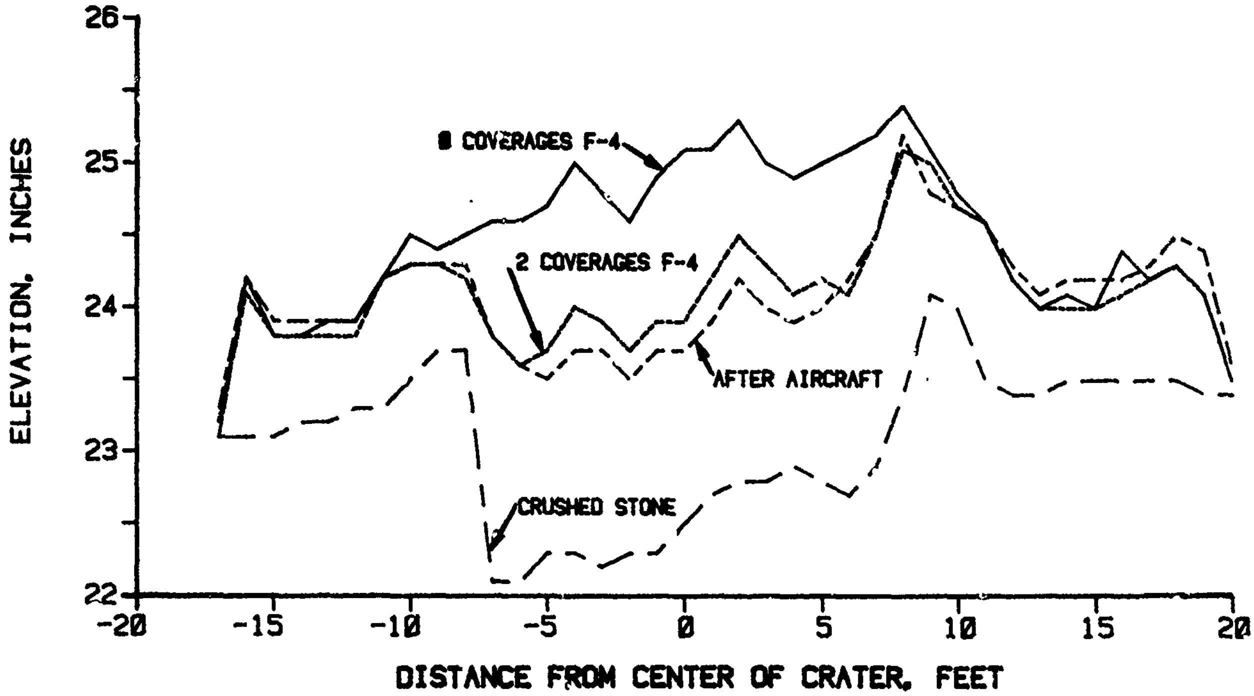


Figure 69. South wheel path profile, FOD cover repair, 0 coverages, 2 coverages of F-4 load cart, and after F-4 aircraft traffic

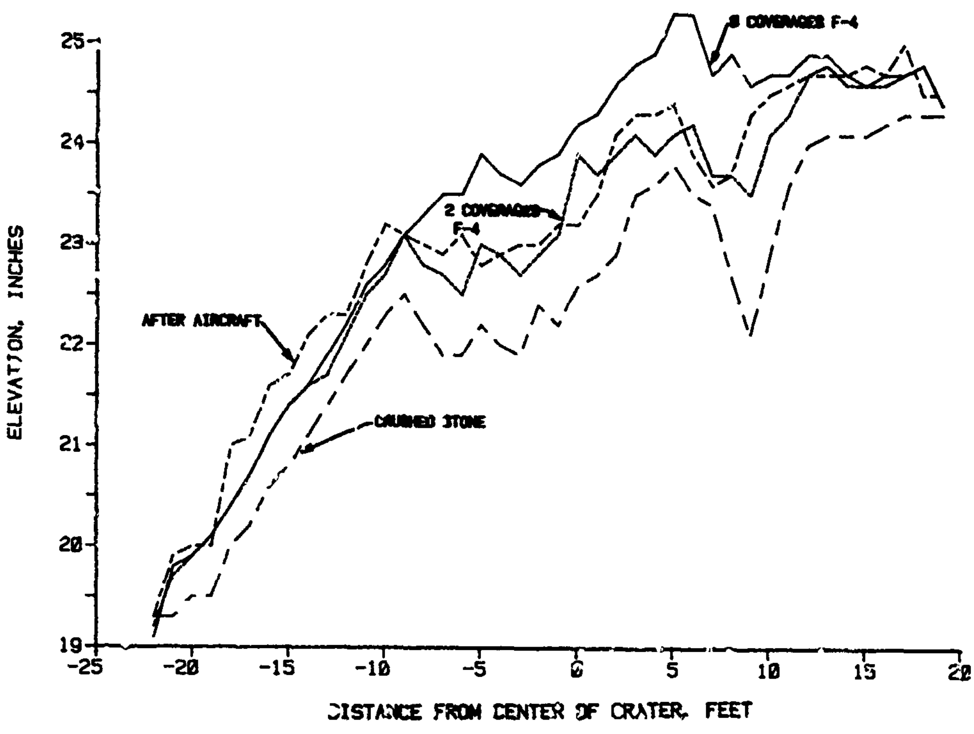


Figure 70. West quarter point cross section, FOD cover repair, 0 coverages, 2 coverages of F-4 load cart, and after F-4 aircraft traffic

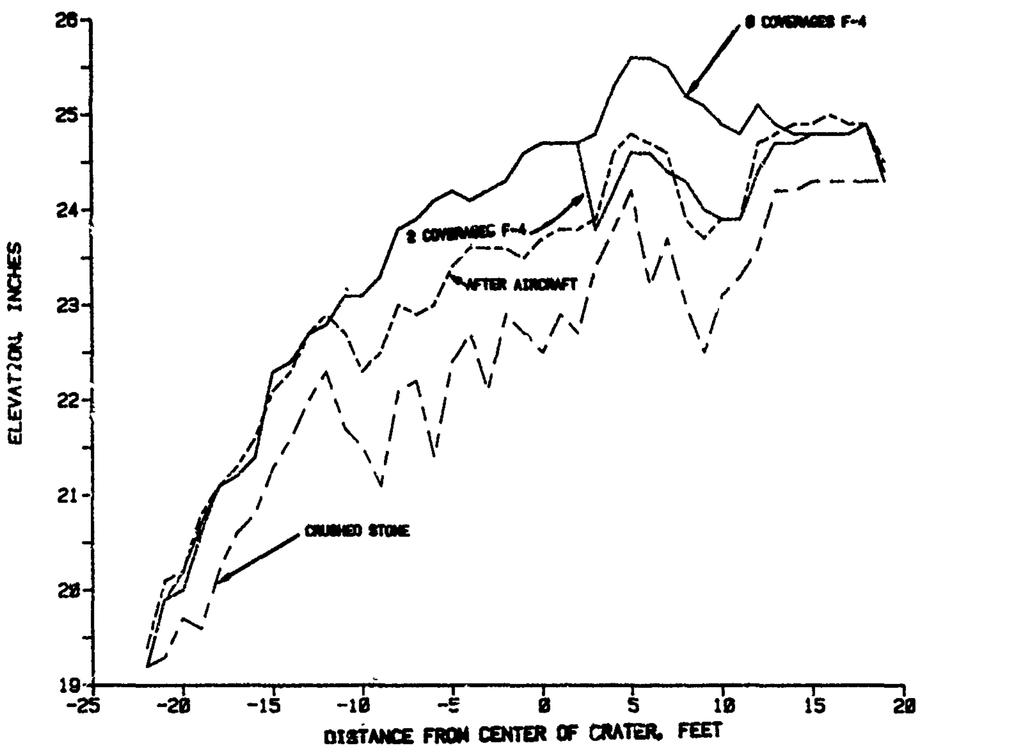


Figure 71. Center cross section, FOD cover repair, 0 coverages, 2 coverages of F-4 load cart, and after F-4 aircraft traffic

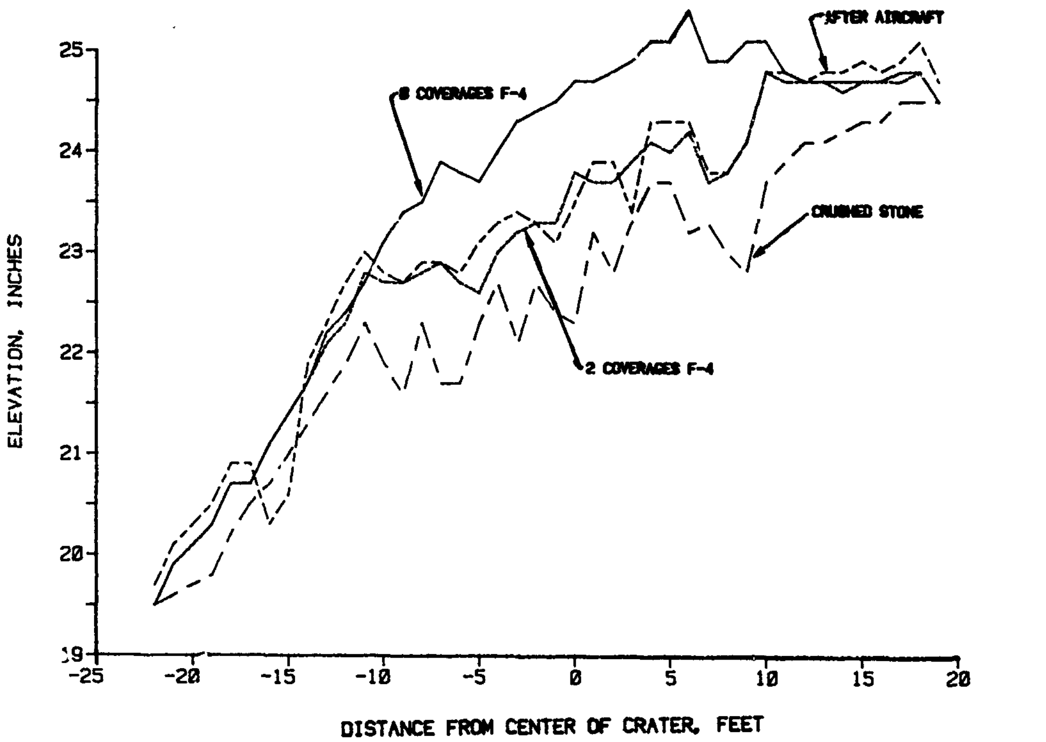


Figure 72. East quarter point cross section, FOD cover repair, 0 coverages, 2 coverages of F-4 load cart, and after F-4 aircraft traffic

wheel was located inside the actual crater. The bow wave was first observed when the load wheel first traversed the south side of the crater and continued until the load wheel had moved approximately 4 ft inside the crater (after about five passes). A bow wave was not observed as proof rolling continued across the remaining 21-ft crater width. After proof loading, two tears were observed in the top ply of the FOD cover. A 10-in. tear (Photo 41) was located 2 ft east of the center of the crater on the crater east-west center line and the other, a 15-in. tear, was located on the third FOD cover hinge from the south edge of the FOD cover (Figure 66). The FOD cover had numerous small ridges or wrinkles (manufacturing defects), most of which contained hairline cracks after the proof loading. Surface roughness measurements without a load show a 1.0- to 2.75-in. upheaval with zero sag after proof loading (two coverages, F-4 load cart); however, loaded measurements using the load wheel on the F-4 load cart show no upheaval and sag measurements that range from 0.8 to 1.2 in. (Table 6). This would indicate that underlying fill material was consolidated during proof loading which resulted in a 0.8- to 1.2-in. void between FOD cover and the fill material. Cross-section plots after two coverages of the F-4 load cart (proof loading) are shown in Figures 67 through 72.

31. The order of F-4 aircraft testing was the same for the FOD cover repair as it was for the precast slab repair (Table 5). Sag measurements recorded after runs 6 and 15 (taxi runs) are shown in Table 6. The maximum sag measured after run 6 was 1.25 in. and after run 15 the maximum sag was 1.5 in. During the touch-and-go phase of the aircraft testing, seven attempts were made to touch down (land) directly on the FOD cover repair and only one came close. Five of the attempts were short; one was over or past the FOD cover repair and on the other attempt, one of the main gears touched down on the southwest corner of FOD cover which was just past the actual crater. Although no full spin-ups of the tires occurred on the crater itself, at least two of the short touch downs were probably effective simulations of landing over the FOD cover repair. Two flights were made with the aircraft in a take-off attitude, with afterburners applied, over the crater repair. On the first flight the after burner came in later and the only distress observed was loose particles blown from the pavement surrounding the repair. On the second flight the afterburners fired directly over the crater repair and blew a 20- by 74-in. piece (top ply of fiberglass) off the trailing edge of the FOD

cover (Photo 42). The loose fiberglass landed approximately 165 ft behind the crater repair. The performance of the FOD cover repair was not affected by the 20- by 74-in. damaged area. After the touch-and-go operations, light and heavy braking runs and a sharp turn maneuver by the aircraft were made on the FOD cover. No additional distress to the FOD cover was observed during these operations. Photo 43 is a general view of the FOD cover repair after the aircraft test runs. Figures 67 through 72 show profile and cross-section plots of the crater repair after aircraft traffic.

32. After aircraft traffic, the FOD cover was removed to obtain data on the base material and then the FOD cover was installed and load cart traffic begun. Photo 44 shows the rutting that had developed in the base course during proof loading and aircraft tests. Plots of the profile and cross-section measurements taken on the base course after aircraft traffic are shown in Figures 67 through 72. The average of five nuclear density tests performed on the base course after the aircraft traffic was 133.6 pcf (Table 2). Surface measurements taken during traffic and recorded in Table 6 indicate that a 1.5-in. maximum sag occurred in the south wheel (gear) path of the F-4 aircraft. Surface roughness measurements recorded after aircraft traffic and compared with those measured before traffic indicate a maximum consolidation of 4.5 in. (3.0-in. upheaval and 1.5-in. sag) had taken place in the wheel paths.

33. The F-4 aircraft test pilot comments about the FOD cover repair were as follows:

- a. Sag was not a problem.
- b. Slippage was not a notable problem on the small FOD cover.
- c. Touch-and-go operations felt the same for all surfaces; they were indistinguishable from normal landing impact.

34. After the profile, cross section and density measurements were recorded on the base material, the FOD cover was replaced, and then F-15 load cart traffic was applied in the 80-in.-wide traffic lane shown in Figure 66. Maintenance was not required on the fill material before replacing the FOD cover. After replacing the FOD cover, surface roughness measurements and profile data were taken along the center line of the traffic lane. The maximum sag measured at this time was 1 in. The 0-coverage profile plot is shown in Figure 73. The 0-coverage cross-section data are plotted and shown in Figures 74 through 76. At the beginning of traffic, tears were observed in the

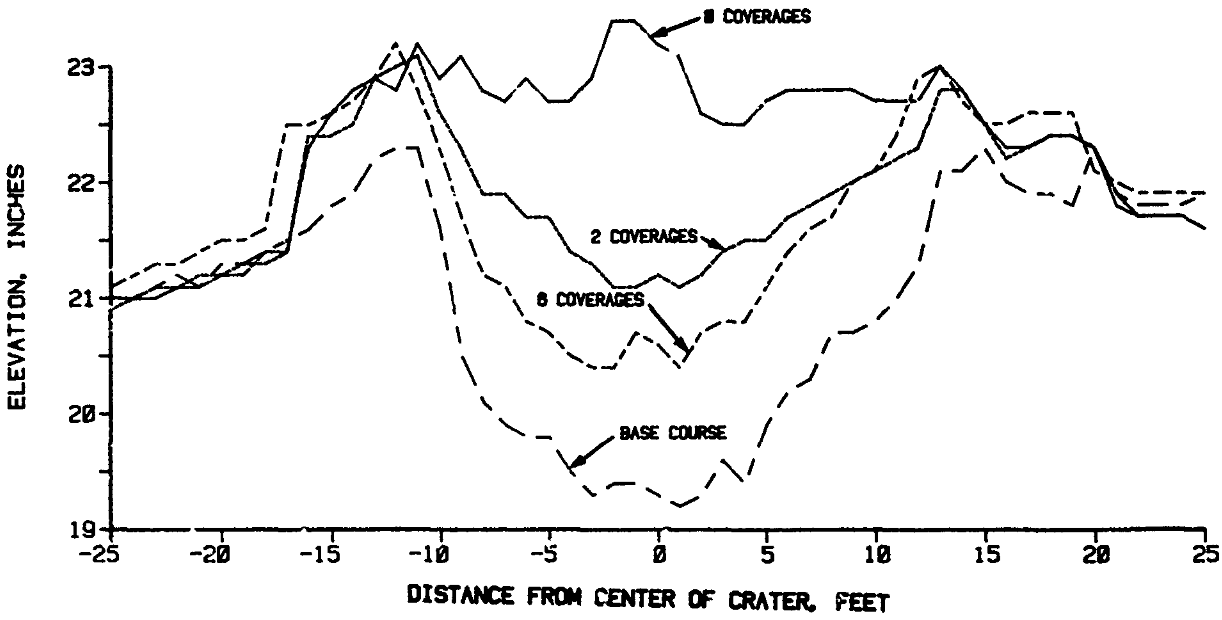


Figure 73. Profile, center of the F-15 traffic lane, FOD cover repair, 0 coverages, 2 coverages, and 6 coverages

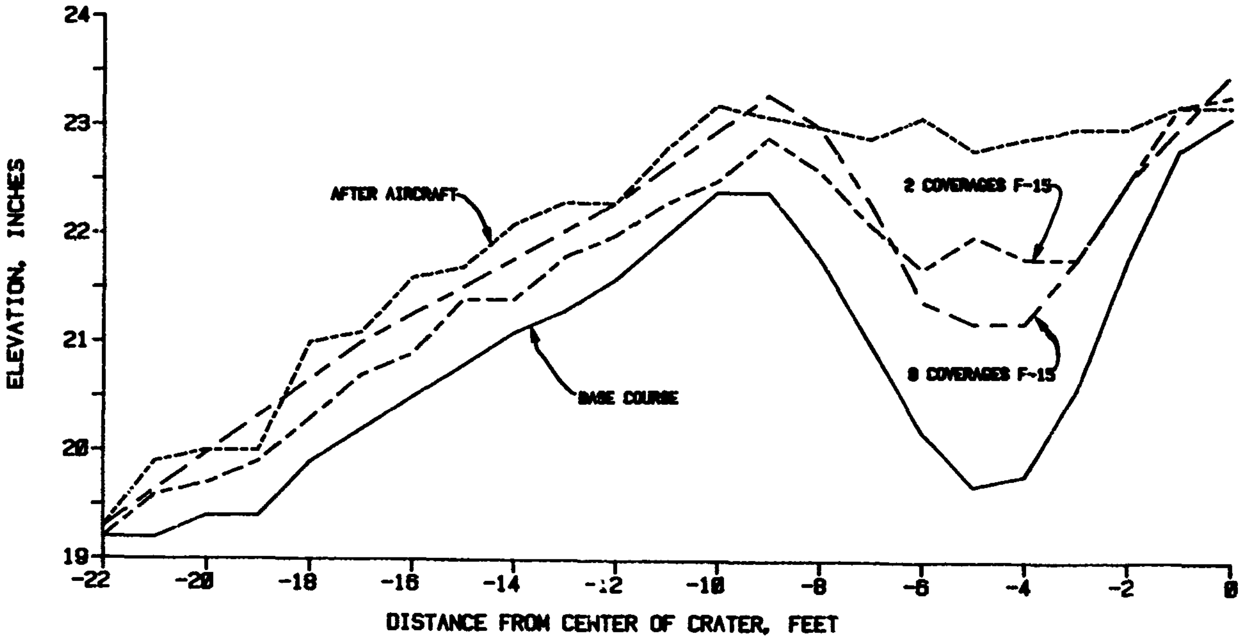


Figure 74. West quarter point cross section, F-15 traffic lane, FOD cover repair, 0 coverages, 2 coverages, and 6 coverages

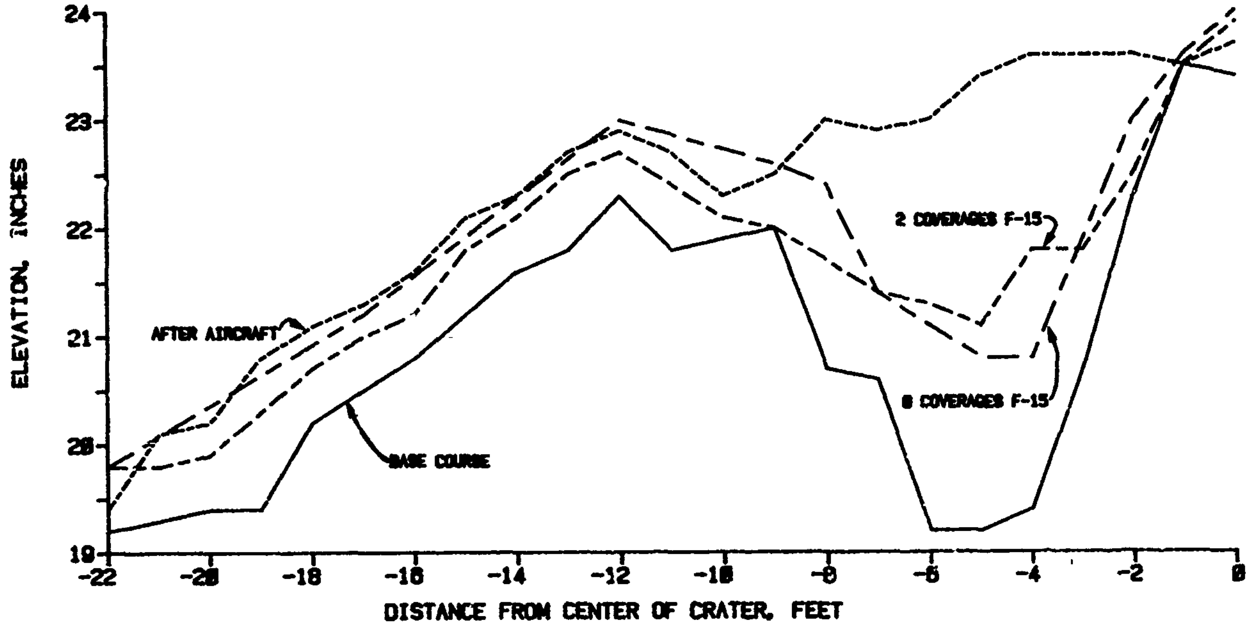


Figure 75. Center cross section, F-15 traffic lane, FOD cover repair, 0 coverages, 2 coverages, and 6 coverages

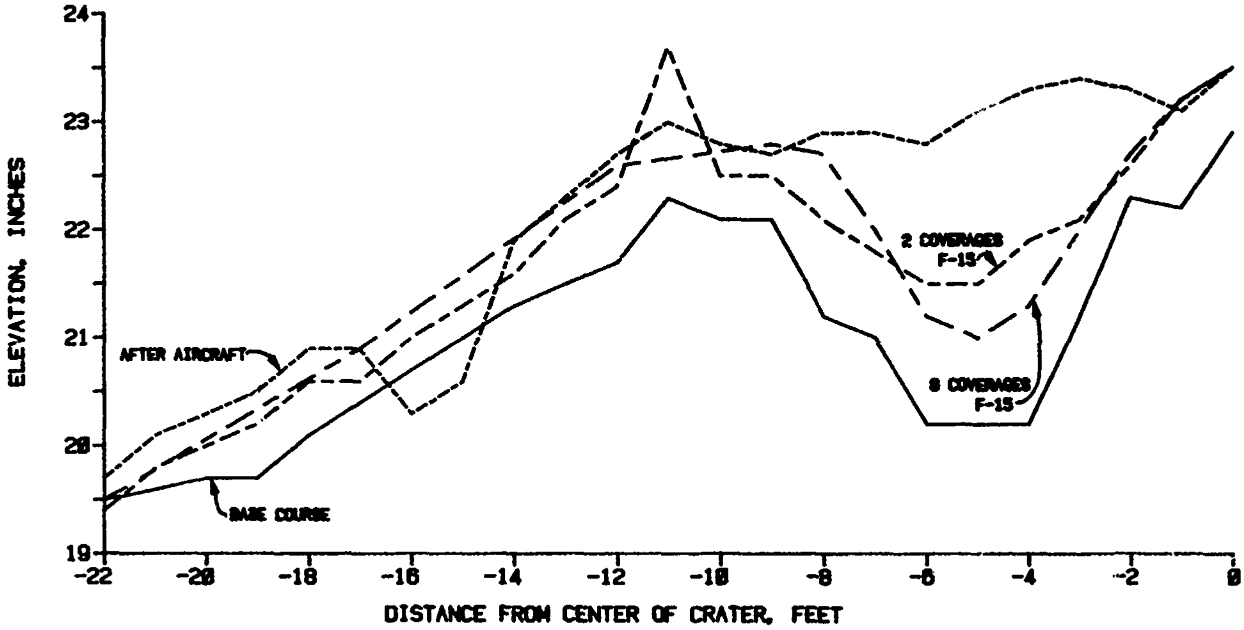


Figure 76. East quarter point cross section, F-15 traffic lane, FOD cover repair, 0 coverages, 2 coverages, and 6 coverages

FOD cover. After two coverages, three tears were detected on the hinge which was in the center of the traffic lane and one tear was located 1 ft south of the hinge. The tears on the hinge were 1, 2, and 5 ft in length. The 5-ft tear was the only one of these tears that was completely through both plies of fiberglass. Although the 5-ft tear was completely through the FOD cover, the base course material remained intact and there was no FOD problem. The tear 1 ft south of the hinge was 1 ft long and only in the top ply of the fiberglass. Photo 45 is a general view of the traffic lane after two coverages. The sag measurement increased from 1.0 to 1.88 in. at this coverage level. The profile and cross-section data measured after two coverages of traffic and shown in Figures 73 through 76 indicate consolidation in the crater fill materials. Between two and four coverages, a low profile bushing, used in anchoring the FOD cover, was discovered under the FOD cover. The bushing was lost under the FOD cover when the cover was replaced after the F-4 aircraft traffic and was discovered when the neck of the bushing punctured the FOD cover. As can be seen in Photo 46, the puncture is located about 8 in. to the right of the ruler and just above the 5-ft tear. The puncture was approximately 1.25 in. in diameter and appeared to be the only damage caused by the bushing even though it was located close to the tear. Traffic was stopped after four coverages so that the 5-ft tear which had increased to 6 ft in length could be patched. The patch consisted of one layer of fiberglass, 19 by 75 in. (Photo 46), which was saturated with polyurethane that had been catalyzed 2 weeks earlier and then placed over the tear. After patching, traffic was continued beginning at the edge of the traffic lane, and on the first pass of the load cart, the patched started to work loose. After four passes, the patch was completely loose. During these four passes of traffic, the closest the load wheel came to the patch was about 16 in. Although the patch had come loose, traffic was continued; and after six coverages, sag measurements were taken. The maximum sag measured at this time was 3.25 in. The maximum sag measurements recorded during all phases of traffic applied on the north side of the crater repair (F-15 traffic lane) are plotted and shown in Figure 77. Photo 47 shows the traffic lane, with a 10-ft straightedge, after the six coverages. The 6-ft-long tear which was patched after four coverages of traffic had increased to 18 ft in length (Photo 48) after six coverages. This 18-ft tear was completely through the FOD cover; however, the base course material was still intact. Five additional tears were observed in the traffic

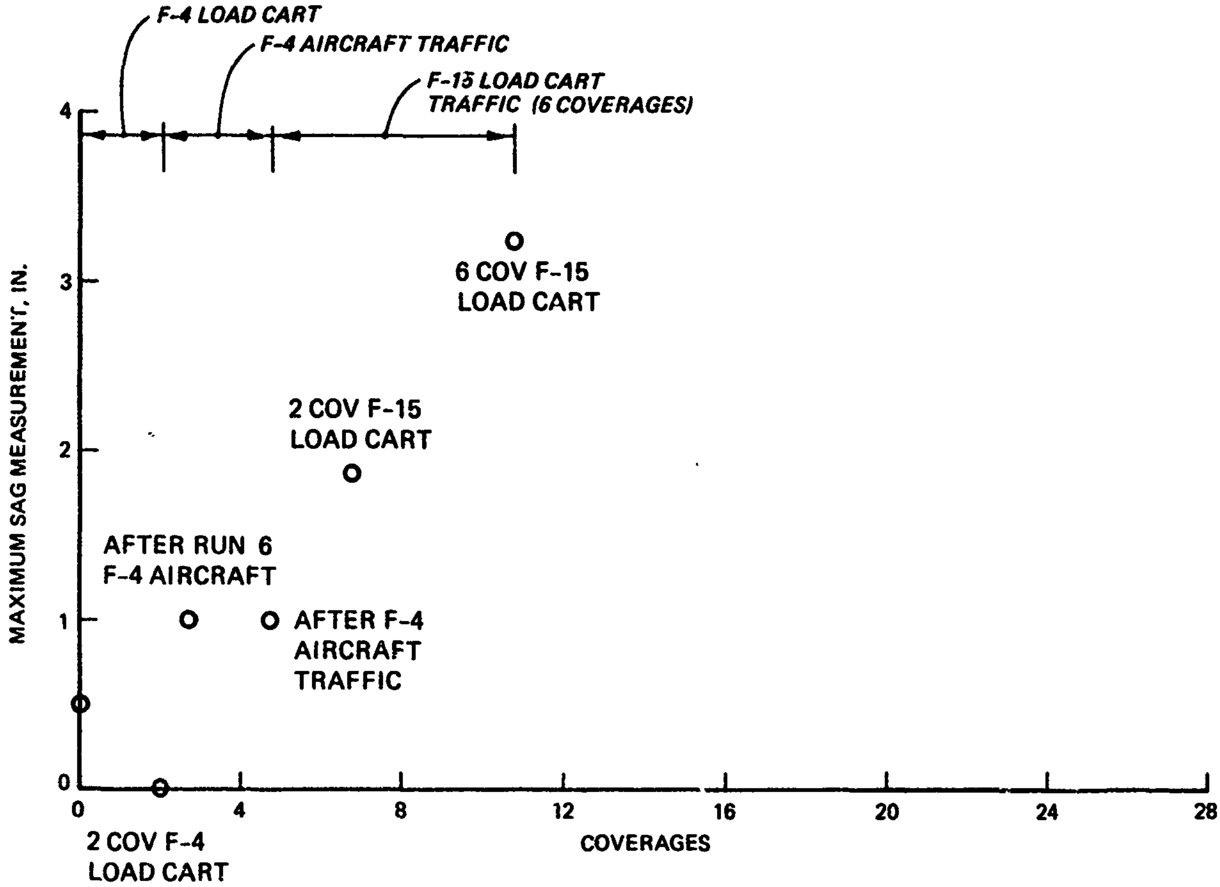


Figure 77. Maximum sag measurements for the north side of the crater repair (F-15 traffic lane)

lane at this time. None of these additional tears was located on a hinge and they ranged in length from 1 to 4 ft. Four of these tears were in the top ply and one tear, 1 ft long, was through both plies. Figures 73 through 76 show profile and cross-section data on the FOD cover and base course (FOD cover removed) for the traffic lane after six coverages.

35. After six coverages, traffic was stopped on the F-15 traffic lane because the peak sag was exceeding 3.0 in. Even without tears, the FOD cover is porous, but with them, large amounts of rainwater entered the base course material and was ponded within the traffic lane. At this time it was decided to apply F-15 load cart traffic along the outside edge of the traffic lane to determine whether the base course was saturated and whether it would not support the load wheel. After several passes along the outside edge, the FOD cover was unaffected by this severe test and less than 1 in. of consolidation had occurred in the base material.

36. After the F-15 load cart traffic, F-4 load cart traffic was applied in the 100-in.-wide traffic lane (Figure 63). As can be determined from Figure 63, an FOD cover hinge was located approximately 20 in. from the north

edge of this traffic lane. The two coverages of F-4 load cart traffic that were placed on the crater repair during the proof testing are included in the following performance data. Photo 49 shows the general condition of the traffic lane after proof testing (2 coverages). It should be noted that due to the previous weather conditions and the poor condition (tears) of the FOD cover in the F-15 traffic lane rainwater was trapped between the FOD cover and base material. Before test traffic was begun in this lane a 0.5-in. sag was measured along the center line of the traffic lane (Table 6). Plots of the profile data recorded along the center line of the traffic lane after various traffic levels are shown in Figure 78 and plots of the cross-section measurements taken during traffic are shown in Figures 79 through 81. The measurements for the plot labeled "2 coverages" in Figure 78 were taken after proof loading and before actual test traffic was applied in the test lane. The plots labeled "6 coverages F-15" in the Figures 79 through 81 are results of measurements recorded across the entire FOD cover width and before actual load cart test traffic was applied in the F-4 traffic lane. The first distress in the FOD cover was observed after six coverages of traffic. This distress included three tears through both plies of fiberglass, one tear in the top ply of fiberglass along the hinge, and damage to a patched portion of the hinge. The tears ranged in length from 1.5 to 3.0 ft. Photo 50 shows two of these tears. The patch damage consisted of the pond between a 8- by 20-in. patch and the hinge becoming loose on the south half of the patch. The maximum sag measured after six coverages of traffic was 1.75 in. As traffic was continued, it was noticed that the fiberglass along the hinge began to spall. This spalling which could possibly be a minor FOD problem was observed between six and ten coverages of traffic. The largest spalled area at this time was approximately 3 by 10 in. Other distresses observed after 10 coverages included the 8- by 20-in. patch which was completely disengaged from the hinge and either additional tears or an increase in length of the tears which occurred after six coverages. Photo 51 shows the surface condition along the hinge after 10 coverages. At this time four tears in the FOD cover hinge totaled 8.9 ft in length and the length of four top ply tears not on the hinge ranged between 1 and 5 ft. The maximum sag measured in the center of the traffic lane and at the hinge after 10 coverages of traffic was 2.13 and 3.00 in., respectively. Plots of the profile and cross-section data taken after 10 coverages of F-4 traffic are shown in Figures 78 through 81. The sag

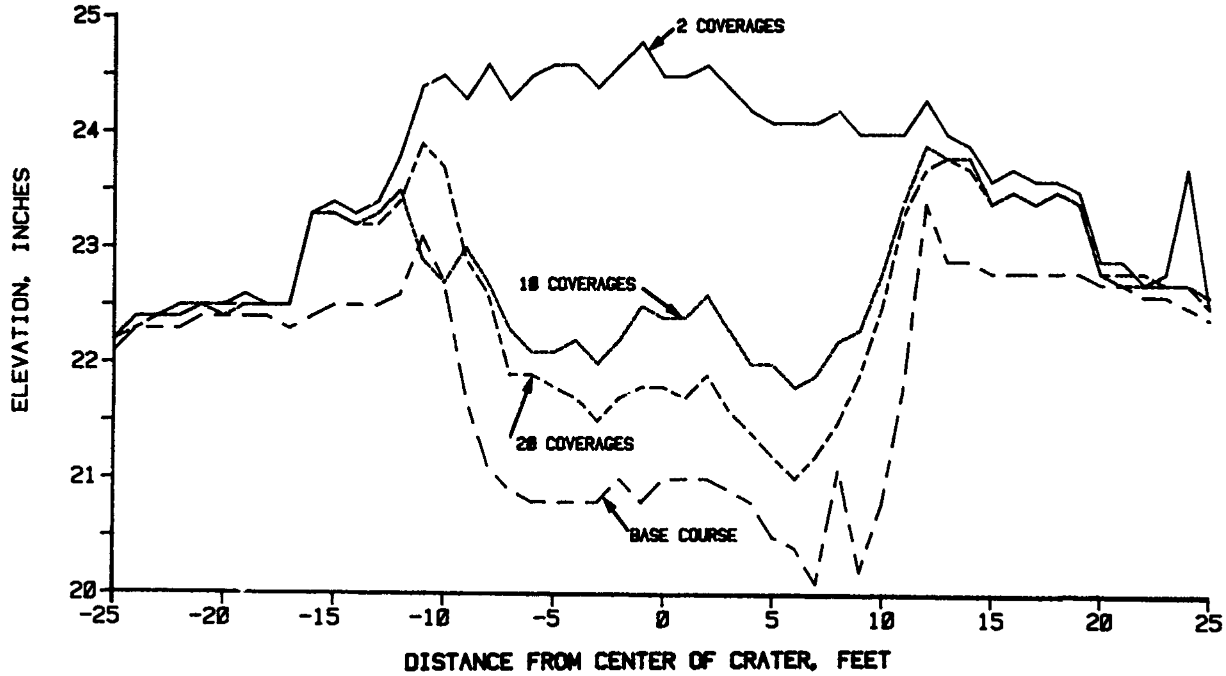


Figure 78. Profile, center of F-4 traffic lane, FOD cover repair, 2 coverages, 10 coverages, and 20 coverages

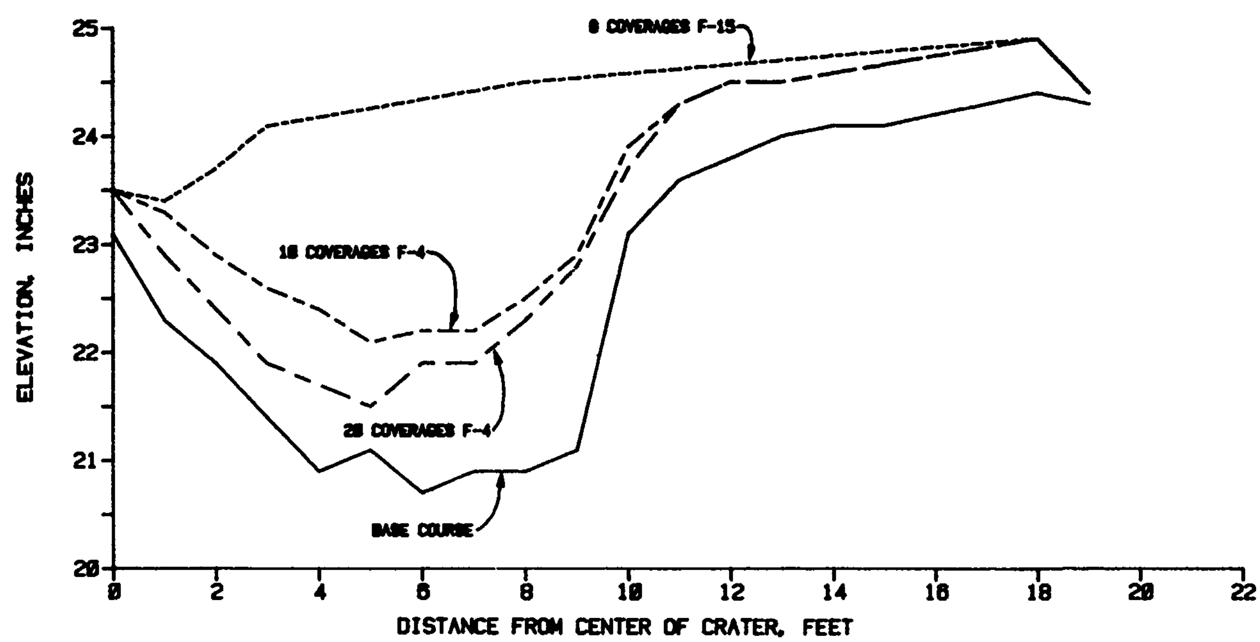


Figure 79. West quarter point cross section, FOD cover repair after 6 coverages of F-15 traffic, 10 and 20 coverages of F-4 traffic

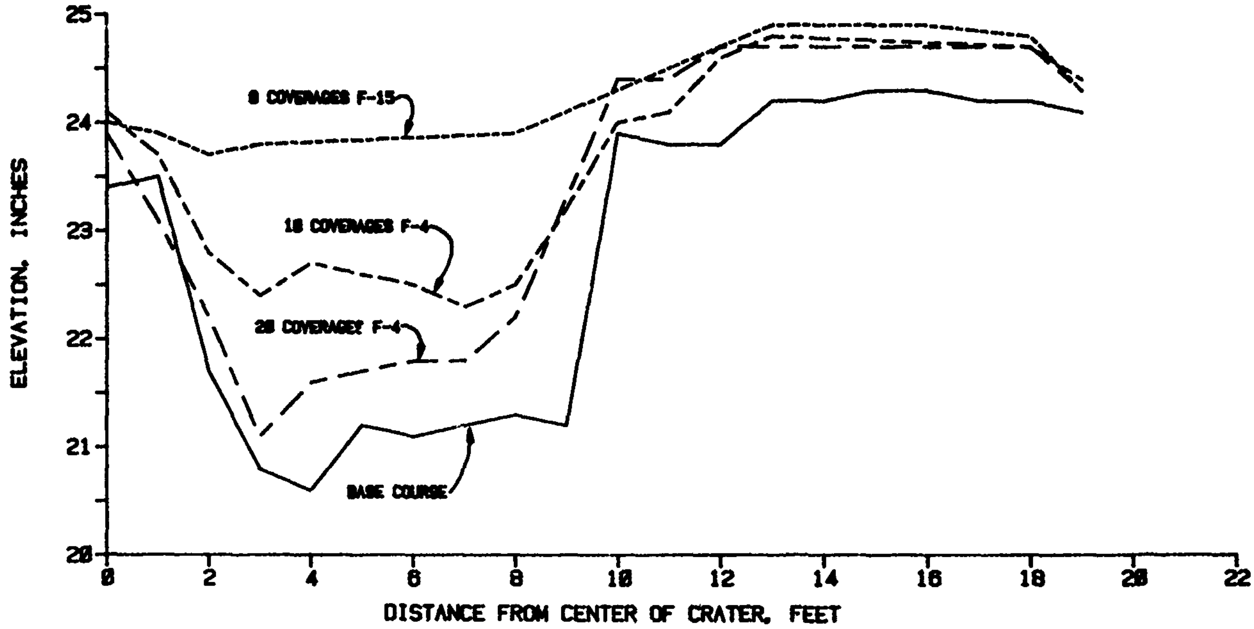


Figure 80. Center cross section, FOD cover repair after 6 coverages of F-15 traffic

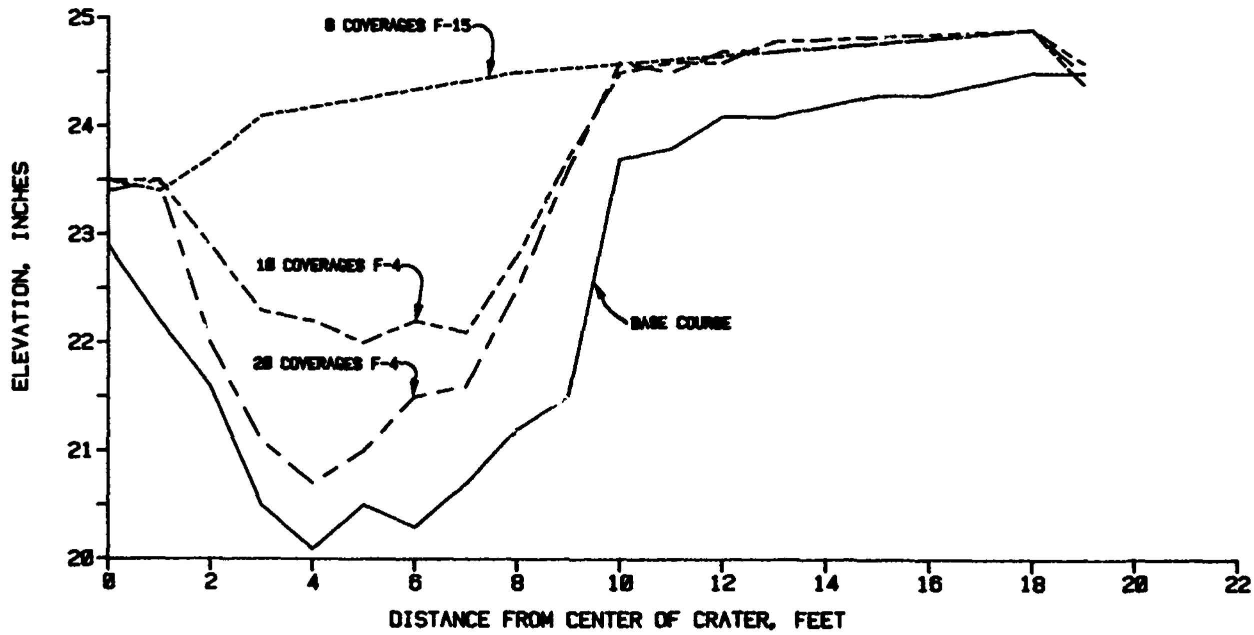


Figure 81. East quarter point cross section, FOD cover repair after 6 coverages of F-15 traffic, 10 and 20 coverages of F-4 traffic

increased as traffic continued. After 16 coverages the sag along the center line of the traffic lane was 2.75 in. Traffic was discontinued after 20 coverages because of high sag measurements and the difficulty of the load cart traversing the test area. The maximum sag measured after 20 coverages along the center line of the traffic lane was 3.0 in. and 3.5 in. along the hinge. The maximum sag measurements recorded during all phases of traffic applied on the south side of the crater repair (F-4 traffic lane) are plotted and shown in Figure 82. Before traffic was stopped, the load cart's pull wheels tended to spin as the load wheel approached and tried to negotiate the transition between the crater and existing PCC pavement. The load cart also leaned from one side to the other as it negotiated this transition. Photo 52 shows a general view of the traffic lane after 20 coverages. After traffic the FOD cover hinge was inspected and found to be torn almost the entire length of the crater and minor spalling of the fiberglass was also observed along the tear. Photo 53 shows a close-up of the torn hinge and spalling. Figures 78 through 81 show profile and cross-section plots taken on the surface of the FOD cover and on the surface of the base material after

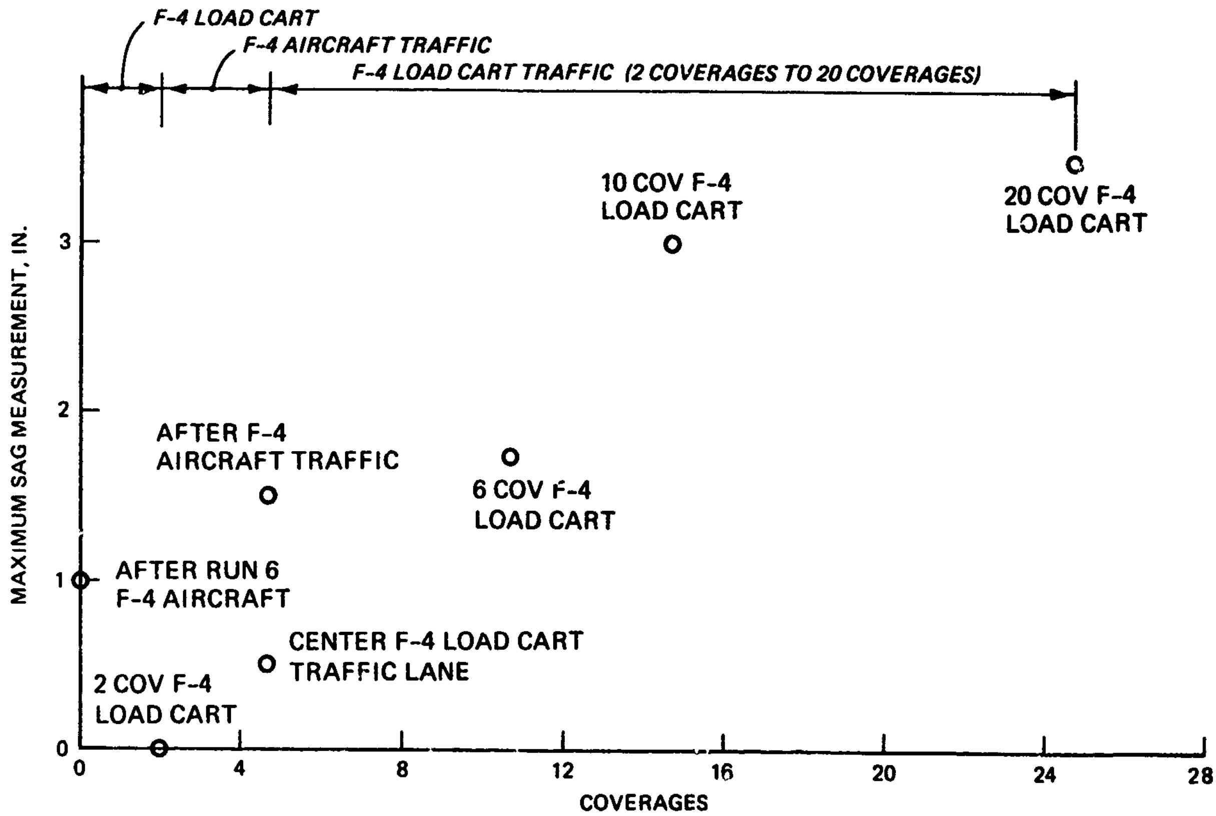


Figure 82. Maximum sag measurements for the south side of the crater repair (F-4 traffic lane)

20 coverages. These data indicate that consolidation occurred under the F-4 traffic. Photo 54 shows the crater repair after the FOD cover had been removed. After the FOD cover was removed, sag measurements were made at the center line of the F-15 and F-4 traffic lanes. Results of these measurements (Table 6) indicate that the maximum sag detected in either of these lanes was 3.5 in.

37. After-traffic CBR's and density determinations were made on the base course and subgrade (silty sand) and the results are shown in Table 2. It should be noted that water had been standing for approximately 12 days in the center of the F-15 traffic lane before CBR measurements were made and that this water was removed just prior to field in-place CBR determinations. Results of the CBR measurements indicate that the strength of the base material after soaking for 12 days was 13 compared to a 26 CBR which was measured out of the area where the water was standing but still inside of the traffic lane. The after-traffic data in Table 2 shows an increase in both CBR's and density, with the exception of the 13 CBR in the center of the F-15 traffic lane, when compared to before-traffic data. The data also show a decrease in the water content of the base course. This decrease in water content along with the consolidation of the base course under traffic was the reason for the increase in CBR's and density. It should be noted that the base material was placed and compacted at a moisture content of 7.3 percent and based on laboratory compaction data, a moisture content of 7.3 percent is 2.0 percent above optimum, which resulted in low densities (132.1 pcf) and low strengths (17 CBR).

38. After the base course across the center of the crater was removed, cross-section data were recorded on the ballast. A plot of this data is shown in Figure 83.

Summary of Findings

39. The findings from traffic testing of the FOD cover repair show that:

a. The crater repair as built (Figures 9 and 10) was underdesigned.

b. The thicknesses of the crater fill material (base course and ballast) were inadequate to withstand the test traffic.

c. Although the test results indicate poor performance of this type of crater repair, the performance would have been

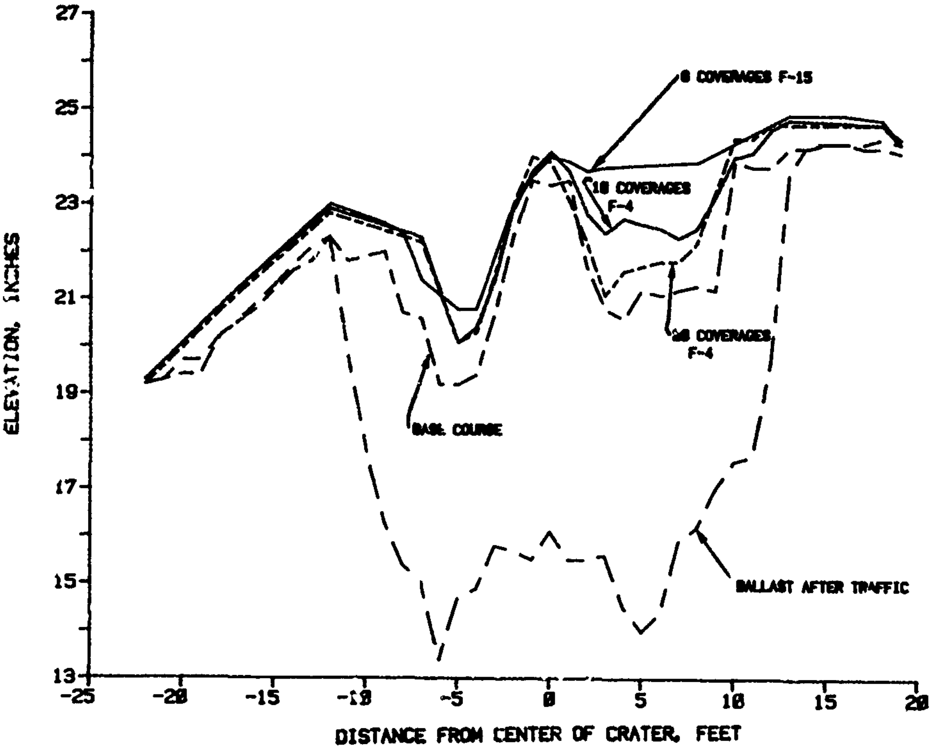


Figure 83. Center cross section, FOD cover repair after 6 coverages of F-15 traffic, 10 and 20 coverages of F-4 traffic

considerably improved if the base material had been constructed at optimum moisture content.

d. The poor performance of the FOD cover under traffic was mainly attributed to hinge problems (tearing and spalling) and could be solved by either eliminating or reinforcing the hinges.

40. Figure 84 shows profile data from the center of the crater repair out 500 ft east. The profile data were taken before any traffic was applied to the crater and were taken along the south wheel path of the F-4 aircraft.

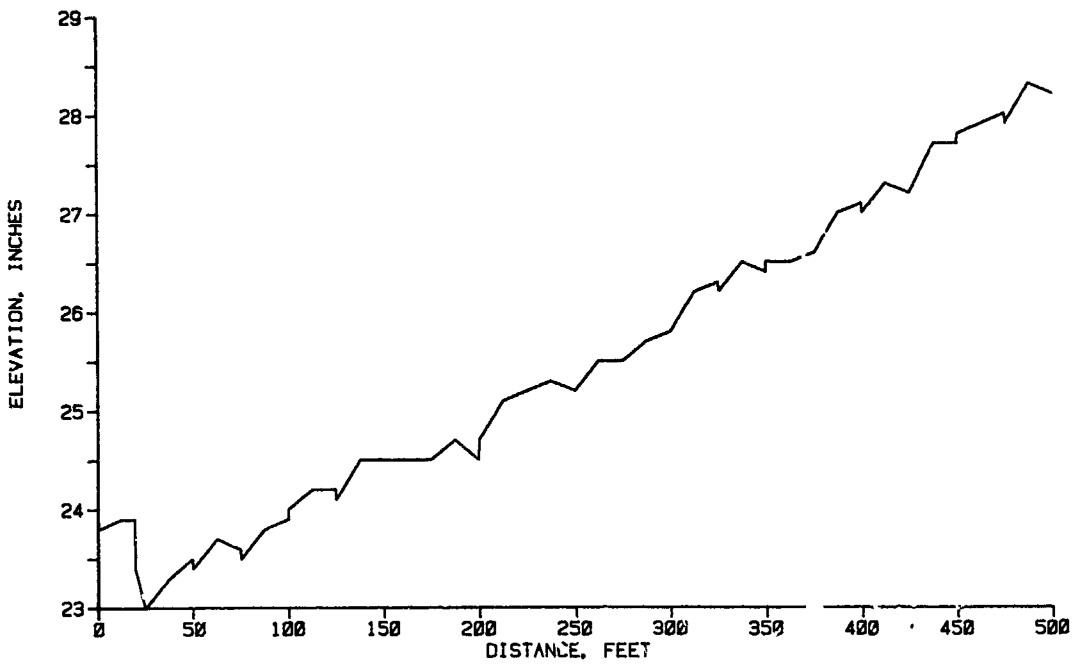


Figure 84. 500-ft lead-in profile, from the center of the crater east, south wheel path F-4 aircraft, FOD cover repair

PART V: CONCLUSIONS

41. This study evaluates two repair techniques for bomb-damaged runways developed by the AFESC and a technique developed by the USAFE. The study consisted of evaluating the constructability by Air Force Teams (Prime BEEF), applying F-4 aircraft traffic, and load cart testing to failure. Based on the findings of this report, the following conclusions are presented:

a. Both F-4 aircraft and load-cart (F-4 and F-15) traffic produced spalling of the precast slabs which could lead to foreign object damage to aircraft engines.

b. To reduce initial slab movement, some compactive effort should be applied to the base and bedding material placed in the crater.

c. The aircraft pilot experienced no control or roughness problems on the slab repair.

d. The thickness of fill material used in the FOD cover repair should be increased to improve the performance under traffic.

e. The poor performance of the prefabricated FOD cover could be attributed to the hinges (areas where the mat was folded) and may be solved by eliminating or reinforcing the hinges.

42. Exact failure points of each repair method with respect to roughness or amount of sag were not analyzed in this study. The above conclusions include recommendations to improve performance of the repair techniques.

Table 1

Density Tests, West Crater

Location	Density pcf	Water Content percent	Modulus of Subgrade Reaction k , pci	Material
		Before Traffic		
Bottom of crater after shot (fallback)	85.8	4.5		Silty sand (curve 3, Figure 3)
After sawing and removal of upheaval				
East side	109.0	8.7		Sand
West side	109.6	16.2		Clayey sand (curve 4, Figure 3)
Leveling course, 1 slab removed	94.2	1.8	88	Crushed granite, (No. 789) (curve 2, Figure 3)
		After Traffic		
Leveling course, all slabs removed	104.3	1.1	368	Crushed granite (No. 789)
After crushed granite removed (No. 789 and ballast rock)				
East side	108.6	7.7		Silty sand
West side	105.1	7.2		Clayey sand

Table 2

Density Tests, East Crater

Location	Density pcf	Water Content percent	CBR percent	Modulus of Subgrade Reaction k , pci	Material
		Before Traffic			
Bottom of crater after shot (fallback)	89.5	6.1			Silty sand (curve 3, Figure 8)
Inside crater	112.8	4.2			Compacted silty sand and ejecta
Center of crater (base)	132.1	7.3	17	175	Well-graded crushed granite (curve 2, Figure 8)
		After F-4 Load Cart Proof Rolling and F-4 Aircraft			
Base under FOD cover	133.6	7.4			Well-graded crushed granite
		After F-15 and F-4 Load Traffic Testing			
Center F-15 traffic lane (6 coverages)	*	7.4	13	**	Well-graded crushed granite (wet)
2.5 feet north of center F-15 traffic lane (6 coverages)	142.7	4.9	26		Well-graded crushed granite
Center of crater between F-4 and F-15 traffic lanes	137.9	4.2	35		Well-graded crushed granite
Center of F-4 traffic lane (20 coverages)	138.4	5.0	33		Well-graded crushed granite
After removal of base and ballast	100.5	5.8			Silty sand

* Density tests were not conducted due to the shape of the rut and the amount of water standing in the rut.

** No modulus of subgrade reaction, k , tests were conduc[illegible] after traffic.

Table 3

Condition of Slabs before Testing

Slab No.	Condition
1	Lifting keyhole bent at bottom of slab and one corner break, 18 in. from the corner
2	A piece of PCC broken out on one side of the slab
3	Lifting keyhole bent
4	Lifting keyhole bent and one corner (PCC) broken off underneath slab
5	Lifting keyholes bent
6	Lifting keyholes bent and one corner break, 18 in. from the corner (not used)
7	A piece of PCC broken out on one side of the slab
8	PCC broken (18 in.) away from angle iron reinforcing
9	Lifting keyholes bent
10	No apparent damage
11	No apparent damage
12	Three pieces of PCC broken out on the sides of the slab and one diagonal crack approximately 5-ft long
13	Angle iron reinforcing broken loose along one edge and a piece of PCC broken out on one side of the slab (not used)
14	Angle iron reinforcing broken loose on two edges and two pieces of PCC broken out on the sides of the slab (not used)
15	Small break on a corner
16	PCC broken off on corner underneath slab
17	Two cracks through center of slab and PCC broken off on corner underneath slab (not used)
18	PCC broken off on corner underneath slab (not used)
19	No apparent damage
20	Angle iron broken loose on one edge and missing on another edge (not used)

(Continued)

Table 3 (Concluded)

Slab No.	Condition
21	PCC broken off on corner underneath slab
22	No apparent damage
23	One diagonal crack
24	No apparent damage
25	No apparent damage
26	One diagonal crack across slab and one crack from the edge of the slab to the center of the slab (not used)
27	No apparent damage (not used)
28	Approximately eight cracks in the slab (not used)
29	Angle iron reinforcing broken loose at one corner and along one edge of the slab (not used)
30	No apparent damage

Table 4

Surface Roughness Measurements, Precast Slab Repair

Traffic Level	Location	Measurement		Date
0 Coverages (no load)	North joint	0.50-in. sag		27 Aug 83
	Center joint	0.50-in. sag		
	South joint	0.25-in. sag		
2 Coverages, F-4 (proofing) (no load)	North joint	0.88-in. sag		27 Aug 83
	Center joint	1.00-in. sag		
	South joint	1.50-in. sag		
Loaded sag measurement F-4 load cart (no load)	Center joint	2.60-in. sag		28 Aug 83
After run 5 F-4 aircraft (no load)	South side of slabs	East corner	West corner	29 Aug 83
	22	0.50-in. sag	0.75-in. sag	
	19	1.13-in. sag	1.13-in. sag	
	12	1.06-in. sag	0.81-in. sag	
	10	0.75-in. sag	0.13-in. sag	
After run 13 F-4 aircraft (no load)	North side of slabs	East corner	West corner	29 Aug 83
	4	--	0.75-in. sag	
	3	0.75-in. sag	1.70-in. sag	
	2	1.50-in. sag	1.63-in. sag	
	1	1.38-in. sag	1.25-in. sag	
	24	1.38-in. sag	--	
	9	--	1.44-in. sag	
	8	0.88-in. sag	1.13-in. sag	
	7	1.63-in. sag	1.56-in. sag	
	23	1.31-in. sag	1.00-in. sag	
	5	0.50-in. sag	--	
After run 14 F-4 aircraft (no load)	South side of slabs	East corner	West corner	29 Aug 83
	21	0.25-in. sag	--	
	22	0.50-in. sag	0.75-in. sag	
	19	1.06-in. sag	1.06-in. sag	
	12	1.00-in. sag	0.81-in. sag	
	10	0.75-in. sag	0.19-in. sag	
	25	0.25-in. sag	0.56-in. sag	
	30	1.00-in. sag	1.50-in. sag	
	16	1.75-in. sag	1.75-in. sag	
	11	1.50-in. sag	1.13-in. sag	
	15	1.13-in. sag	--	
	4	--	0.75-in. sag	
	3	0.81-in. sag	1.63-in. sag	
	2	1.63-in. sag	1.75-in. sag	
	1	2.13-in. sag	1.44-in. sag	
	24	1.50-in. sag	0.13-in. sag	
	North side of slabs	East corner	West corner	29 Aug 83
	9	--	0.38-in. sag	
	8	0.81-in. sag	1.13-in. sag	
	7	1.56-in. sag	1.50-in. sag	
	23	1.25-in. sag	0.94-in. sag	
	5	0.88-in. sag	--	

(Continued)

Table 4 (Continued)

Traffic Level	Location	Measurement		Date
After run 15 F-4 aircraft (no load)	South side of slabs	East corner	West corner	29 Aug 83
	2	--	1.75 in. sag	
	1	2.06-in. sag	1.44-in. sag	
	24	1.50-in. sag	--	
After repair (no load)	South side of slabs	East corner	West corner	29 Aug 83
	25	0.32-in. sag	0.63-in. sag	
	30	1.13-in. sag	1.56-in. sag	
	16	1.50-in. sag	1.56-in. sag	
	11	1.56-in. sag	1.13-in. sag	
	15	1.19-in. sag	--	
	4	--	0.75-in. sag	
	3	0.88-in. sag	1.69-in. sag	
	2	1.63-in. sag	1.81-in. sag	
	1	1.81-in. sag	1.81-in. sag	
	24	1.25-in. sag	--	
2 Co[illegible]-15 ([illegible])	Joint in traffic lane	1.75-in. sag		31 Aug 83
10 Coverages, loaded sag measurements, F-15 load cart	Load on slabs			
	12	Southeast corner 2.85-in. sag		
	16	Northwest corner 3.00-in. sag		
	11	Northwest corner 2.70-in. sag		
	11	Northeast corner 2.73-in. sag		
10 Coverages, F-15 (no load)	Joint in traffic lane	2.50-in. sag		31 Aug 83
14 Coverages, F-15 (no load)	Joint in traffic lane	4.63-in. sag (max.)		1 Sep 83
	South side slab 15	2.50-in. sag		
	North side of slabs			
	11	4.56-in. sag		
	16	3.50-in. sag		
	30	1.75-in. sag		
16 Coverages, F-15 (no load)	Joint in traffic lane	5.25-in. sag		3 Sep 83
	South side of slab 15	2.56-in. sag		
	North side of slabs			
	11	3.13-in. sag		
	16	5.25-in. sag		
	30	3.75-in. sag		
	25	2.25-in. sag		
2 Coverages, F-4 (no load)	Joint in traffic lane	1.81-in. sag		7 Sep 83

(Continued)

Table 4 (Concluded)

Traffic Level	Location	Measurement		Date
6 Coverages, F-4	Joint in traffic lane	3.75-in. sag		7 Sep 83
10 Coverages, F-4 (no load)	Joint in traffic lane	4.38-in. sag		7 Sep 83
10 Coverages, F-4 (no load)	North side of slabs	East corner	West corner	
	5	1.00-in. sag	--	
	23	3.00-in. sag	--	
	7	3.50-in. sag	3.75-in. sag	
	8	1.63-in. sag	--	
20 Coverages, F-4 (no load)	Joint in traffic lane	4.00-in. sag		7 Sep 83
24 Coverages, F-4 (no load)	Joint in traffic lane	4.50-in. sag		7 Sep 83
30 Coverages, F-4 (no load)	Joint in traffic lane	4.50-in. sag		7 Sep 83
36 Coverages, F-4 (no load)	Joint in traffic lane	4.50-in. sag		8 Sep 83
50 Coverages, F-4 (no load)	Joint in traffic lane	5.00-in. sag		8 Sep 83
Slabs removed	North joint (F-15 lane)	11.00-in. sag		10 Sep 83
	Center joint (between load cart lanes)	10.25-in. sag		
	South joint (F-4 lane)	10.88-in. sag		

(Sheet 3 of 3)

Table 5

F-4 Aircraft Events

Run No.	Load kips	Event	Speed knots	Comments	Date
1	50.8	Taxi	10-15	Nose gear center line both repairs	29 Aug 83
2	50.4	Taxi	10-15	Nose gear center line both repairs	
3	50.1	Taxi	10-15	Right gear center of one row of slabs	
4	49.9	Taxi	10-15	Right gear center of precast slab repair	
5	49.6	Taxi	10-15	Right gear center of precast slab repair	
6	48.2	Taxi	10-15	Right gear center of precase slab repair	
11	47.4	Taxi	20	Right gear center of precast slab repair	
12	47.4	Taxi	30	Right gear center of precast slab repair	
13	47.2	Taxi	40	Right gear center of precast slab repair	
14	46.9	Taxi	50	Right gear center of precast slab repair	
15	45.9	Taxi	60	Nose gear center line both repairs	
22		Touch-and-go (landing)	160	FOD cover, short - 150 ft	
23-1 23-2 23-3 23-4		Touch-and-go (landing)	160	FOD cover, short - 225 ft Short - 120 ft, nose gear touchdown on FOD cover, short of FOD cover	
24-1 24-2		Touch-and-go (landing)	160	Precast slabs, short - 130 ft Hit slabs 5 and 25	
25		Touch and go (landing)	160	Precast slabs 3-ft short slab 21	

(Continued)

Table 5 (Concluded)

Run No.	Load kips	Event	Speed knots	Comments	Date
26		Touch-and-go (takeoff)	160	FOD cover	
27		Touch-and-go	160	FOD cover blasted off a piece of the FOD cover (20 by 74 in.	29 Aug 83
28		Touch-and-go (takeoff)	160	Precast slabs	
		(landing)	160	One gear touchdown on the southwest corner of the FOD cover	
29		Touch-and-go (takeoff)	160	Precast slabs	
		(landing)	160	Landing past FOD cover	
37		Sharp turn	5-10	FOD cover	30 Aug 83
41		Light braking	20	FOD cover	
42		Light braking	20	FOD cover	
43		Light braking	20	Precast slabs	
44		Light braking	20	Precast slabs	
45		Heavy braking	45-50	FOD cover	
46		Heavy braking	45-50	Precast slabs	
47		Heavy braking	45-50	FOD cover	
48		Heavy braking	45-50	Precast slabs	

Table 6

Roughness Measurements, FOD Cover Repair

Traffic Level	Location	Measurement	Date
0 Coverages (no load)	North wheel path	3.00-in. upheaval; 0.5-in. sag	27 Aug 83
	Center nose gear	1.00-in. upheaval; 0 sag	
	South wheel path	2.50-in. upheaval; 1.0-in. sag	
2 Coverages, F-4 load cart (no load)	North wheel path	2.50-in. upheaval; 0 sag	
	Center nose gear	2.75-in. upheaval; 0 sag	
	South wheel path	1.00-in. upheaval; 0 sag	
Load sag measurement, F-4 load cart	North wheel path	1.00-in. sag*	
	Center wheel path	0.80-in. sag	
	South wheel path	1.20-in. sag	
After run 6 F-4 aircraft (no load)	North wheel path	1.00-in. sag	29 Aug 83
	Center nose gear	1.00-in. sag	
	South wheel path	1.25-in. sag	
After run 15 F-4 aircraft (no load)	North wheel path	1.00-in. sag	
	Center nose gear	1.00-in. sag	
	South wheel path	1.50-in. sag	
After touch and go's F-4 aircraft (no load)	North wheel path	1.00-in. sag	
	Center wheel path	1.00-in. sag	
	South wheel path	1.50-in. sag	
After F-4 aircraft FOD cover removed	North wheel path	1.00-in. sag	30 Aug 83
	Center nose gear	0.50-in. sag	
	South wheel path	1.50-in. sag	
0 Coverage, F-15 (no load)	Center traffic lane	1.00-in. sag	31 Aug 83
2 Coverages, F-15 (no load)	Center traffic lane	1.88-in. sag	
6 Coverages, F-15 (no load)	Center traffic lane	3.25-in. sag	
2 Coverages, F-4 (no load)	Center of traffic lane	0.50-in. sag	7 Sep 83
6 Coverages, F-4 (no load)	Center of traffic lane	1.75-in. sag	
10 Coverages, F-4 (no load)	Center of traffic lane	2.13-in. sag	
10 Coverages, F-4 (no load)	Hinge inside traffic lane	3.00-in. sag	
20 Coverages, F-4 (no load)	Center of traffic lane	3.00-in. sag	
20 Coverages, F-4 (no load)	Hinge inside traffic lane	3.50-in. sag	
6 Coverages, F-15 FOD cover removed	Center of traffic lane	3.50-in. sag	
20 Coverages, F-4 FOD cover removed	At hinge location inside traffic lane	3.50-in. sag	

* No upheaval measurements were recorded from this point.

Photo 1. Crater to be repaired with precast slabs

Photo 2. Removing debris from around the crater, precast slab repair

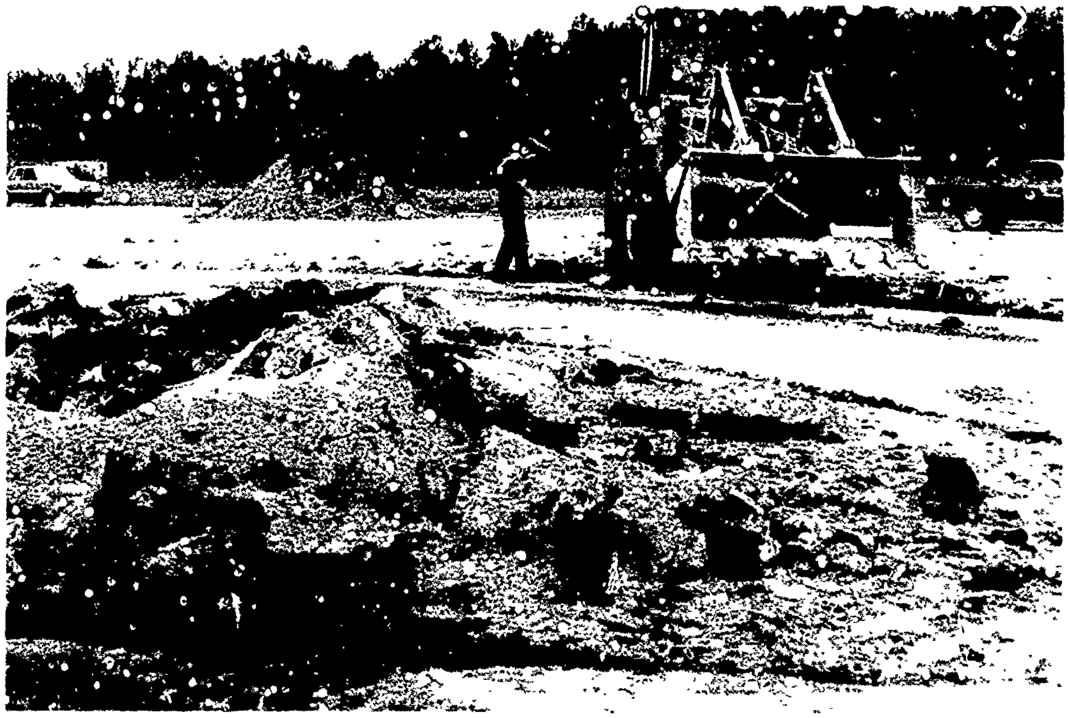


Photo 3. Removing large pieces of debris from precast slab repair crater

Photo 4. Sawing original PCC to square up precast slab crater

Photo 5. Removing PCC between saw cut and original crater, precast slab repair

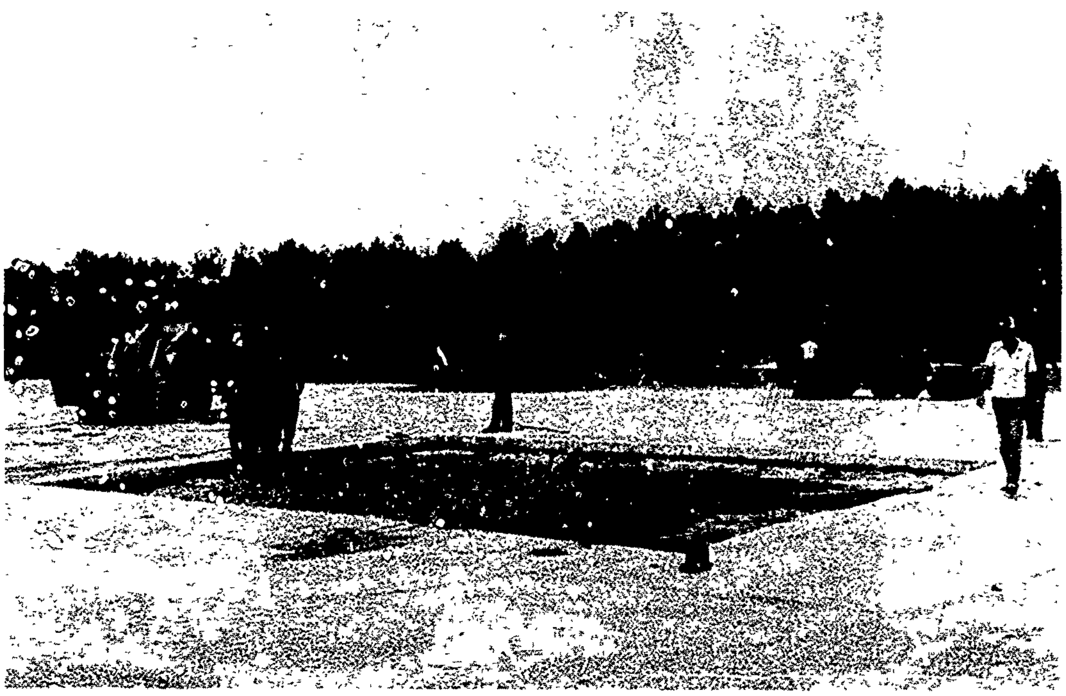


Photo 6. Precast slab repair after placement of ballast

Photo 7. Precast slab repair with some of the leveling course in place and an area outside of the repair that requires patching with Silikal

Photo 8. Screed boards and pipe set to screed for the first row of slabs in the precast slab repair

Photo 9. Screeding leveling course in the precast slab repair

Photo 10. Placement of the first slab in the precast slab repair

Photo 11. Screeding of the leveling course for the second row of slabs in the precast slab repair

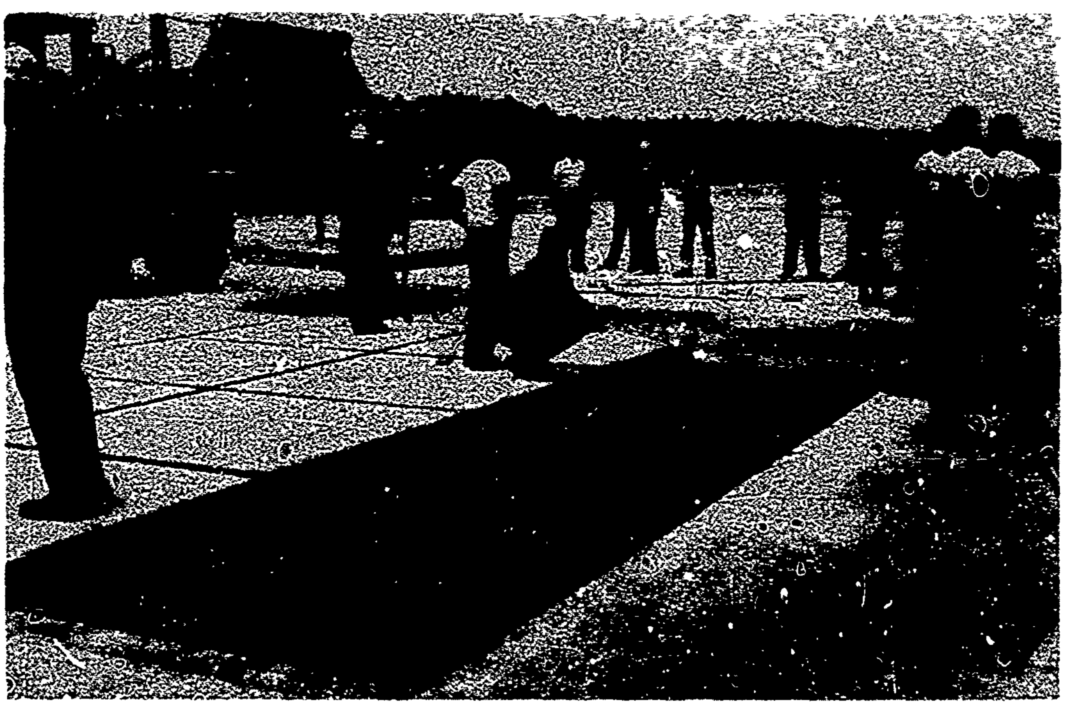


Photo 12. Screeding of the leveling course for the last row of slabs in the precast slab repair

Photo 13. Sand being washed into the joints of the precast slab repair

Photo 14. Filling the large space between the precast slabs and the edge of the crater with leveling course material

Photo 15. The crater formed for the FOD cover repair

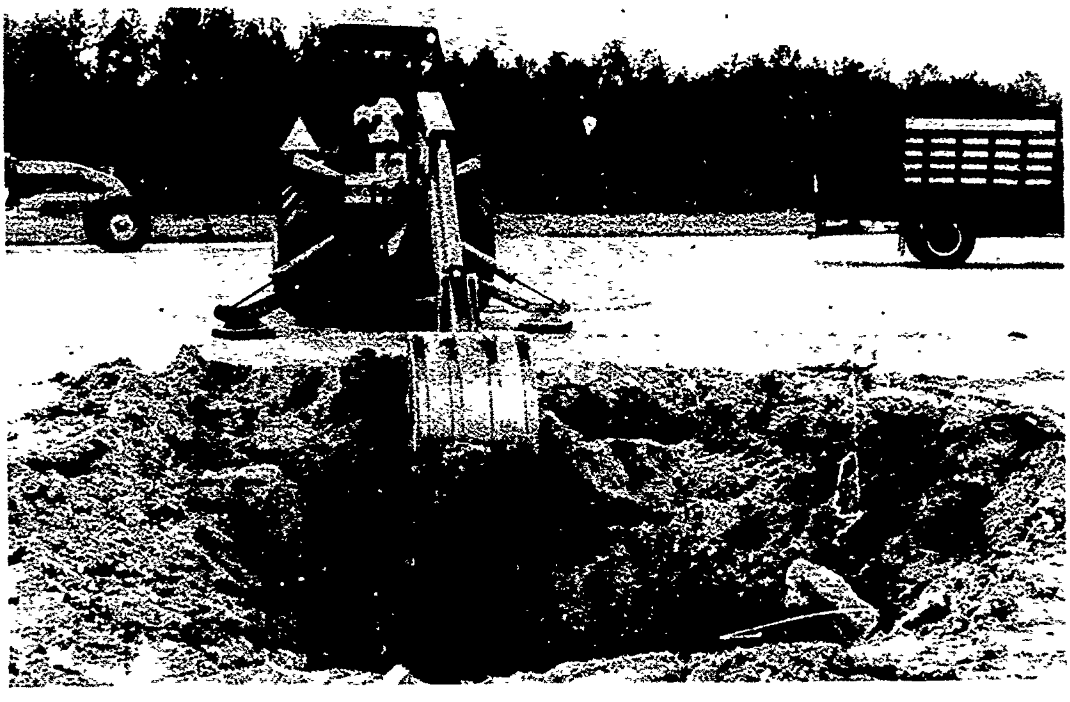


Photo 16. Backhoe pushing ejecta and silty sand into the FOD cover repair

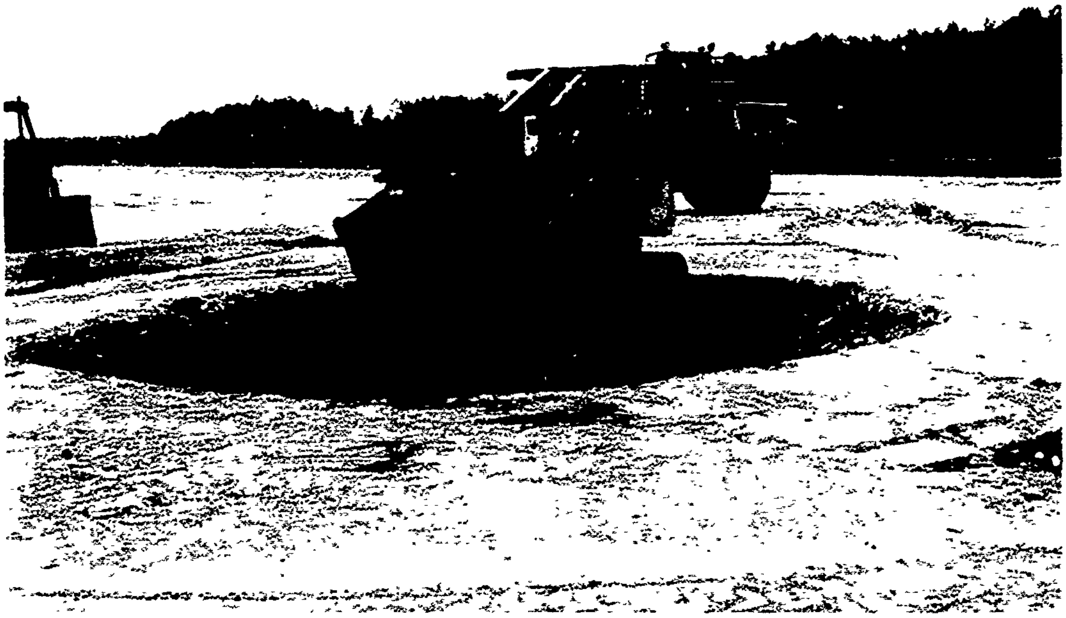


Photo 17. Compacing ejecta in the FOD cover repair

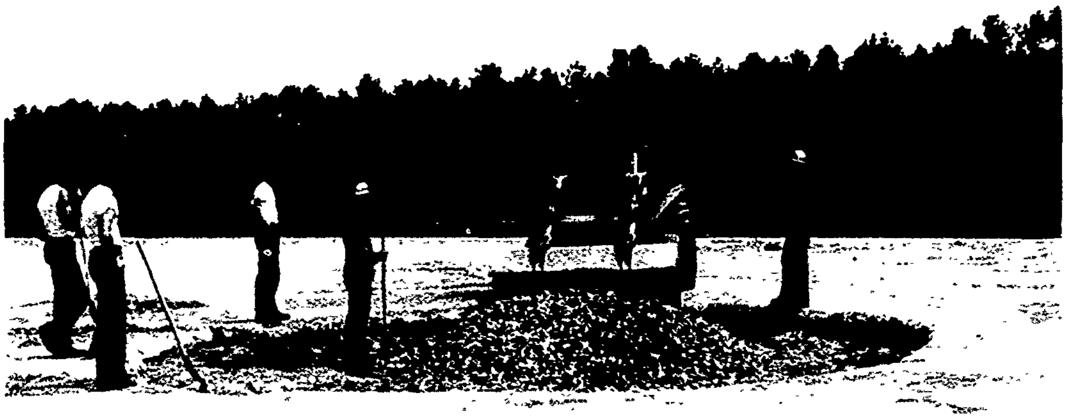


Photo 18. Spreading ballast in FOD cover repair

Photo 19. FOD cover repair with ballast in place

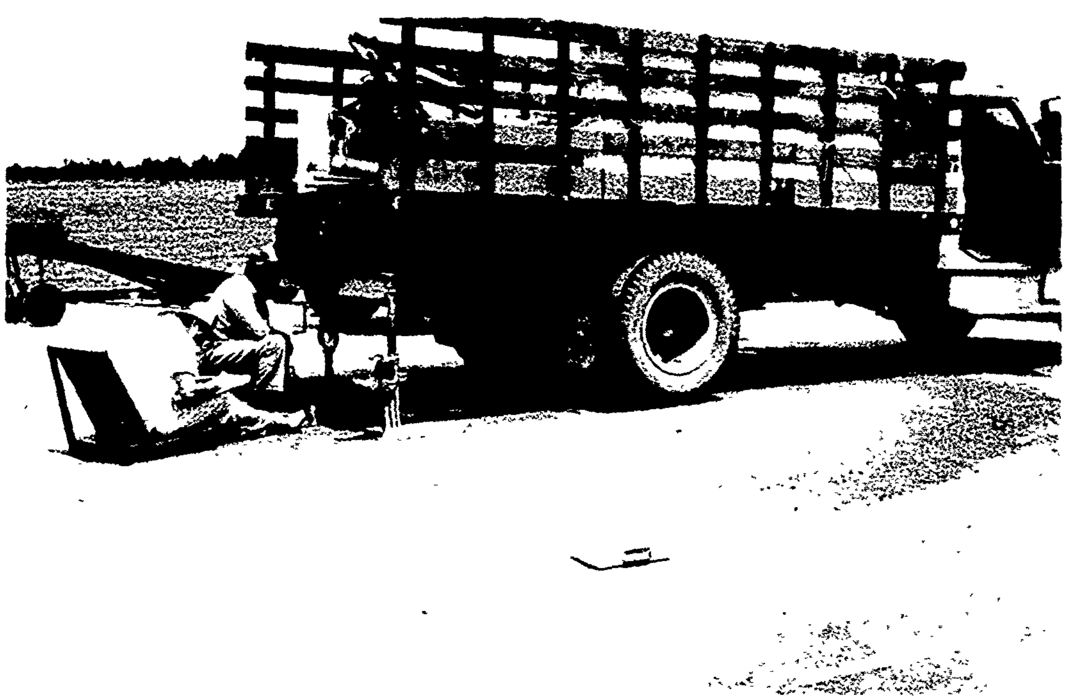


Photo 20. CBR measurements being taken on well-graded crushed granite base, FOD cover repair

Photo 21. Modulus of subgrade reaction, k , on the well-graded crushed granite base, FOD cover repair

Photo 22. FOD cover being towed over crater repair

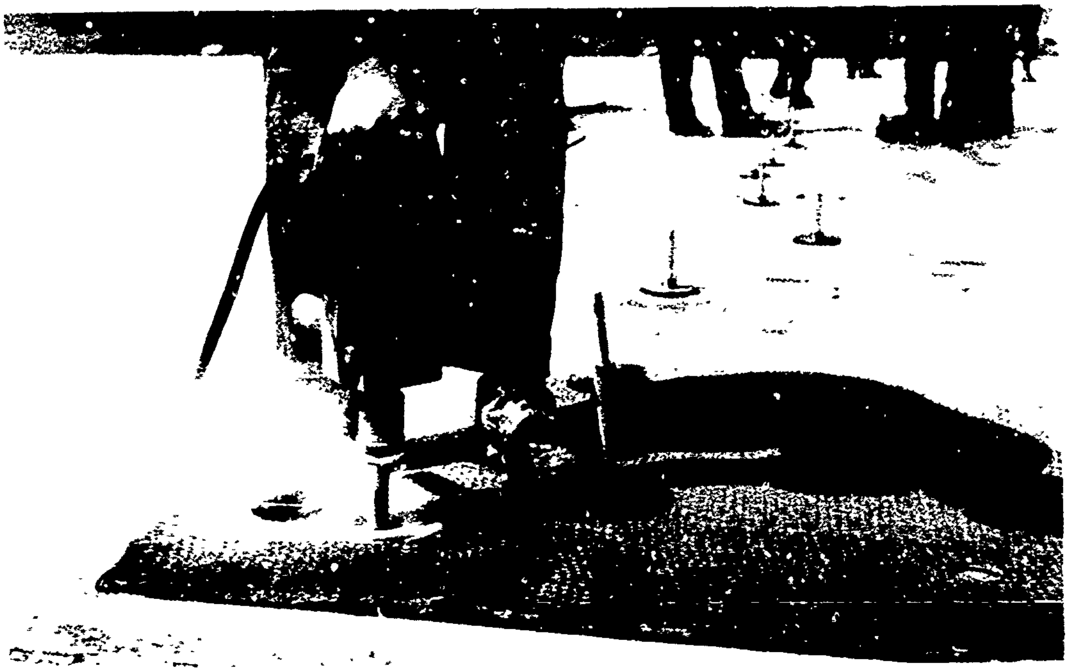


Photo 23. Drilling holes in original PCC to anchor FOD cover

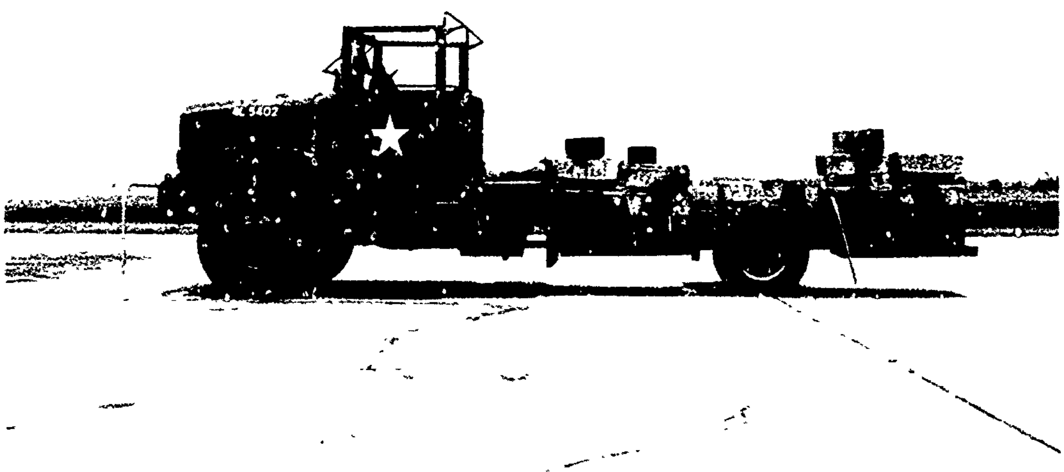


Photo 24. Load cart used to apply traffic

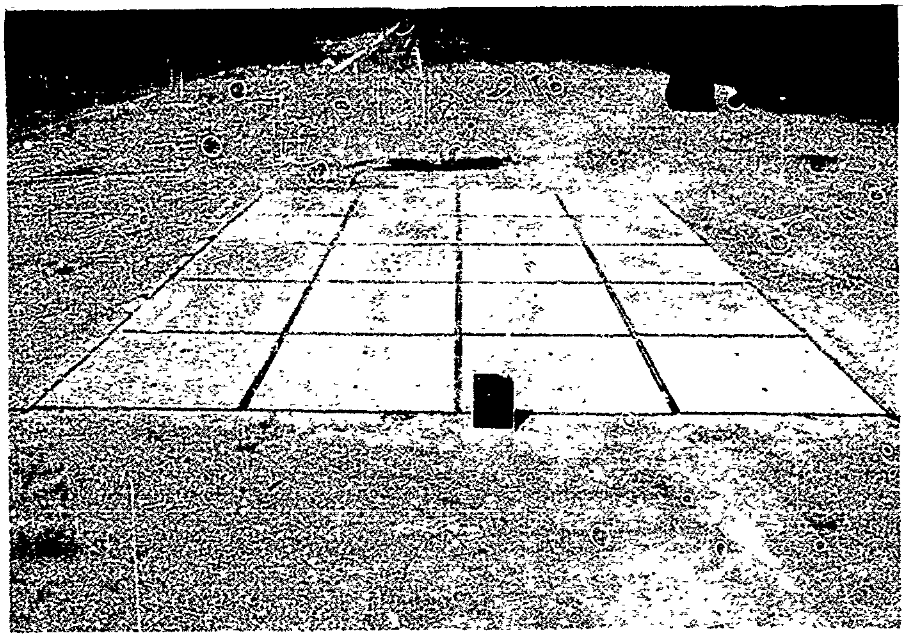


Photo 25. Precast slab repair before traffic

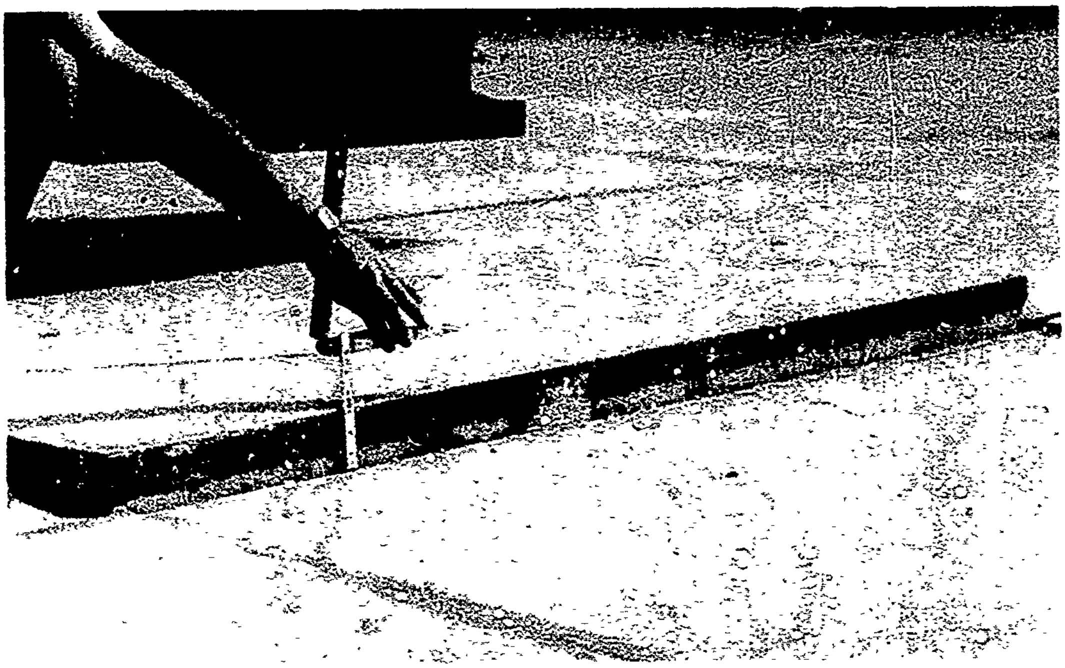


Photo 26. Slab movement after initial proof-testing, precast slab repair

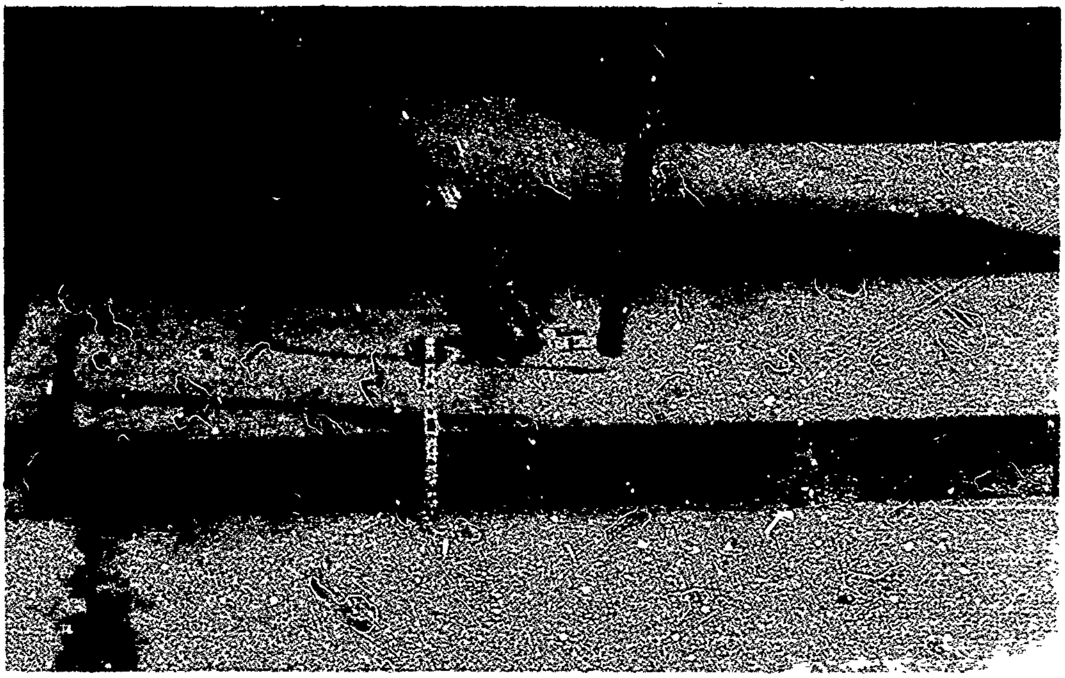


Photo 27. Close-up of slab movement after initial proof-testing, precast slab repair

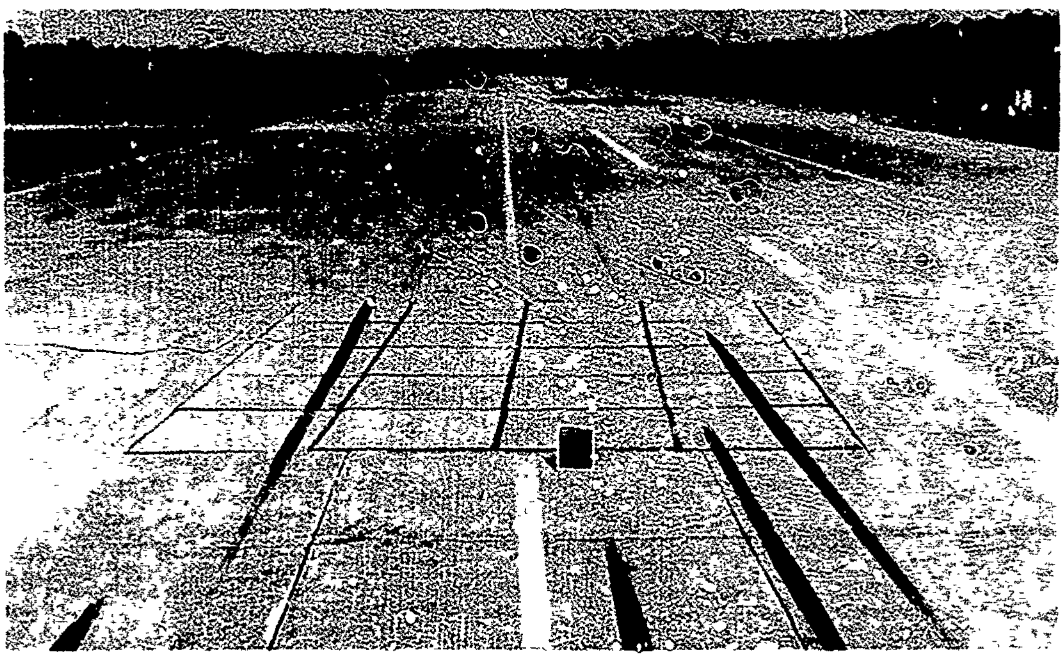


Photo 28. Precast slab repair after F-4 aircraft traffic

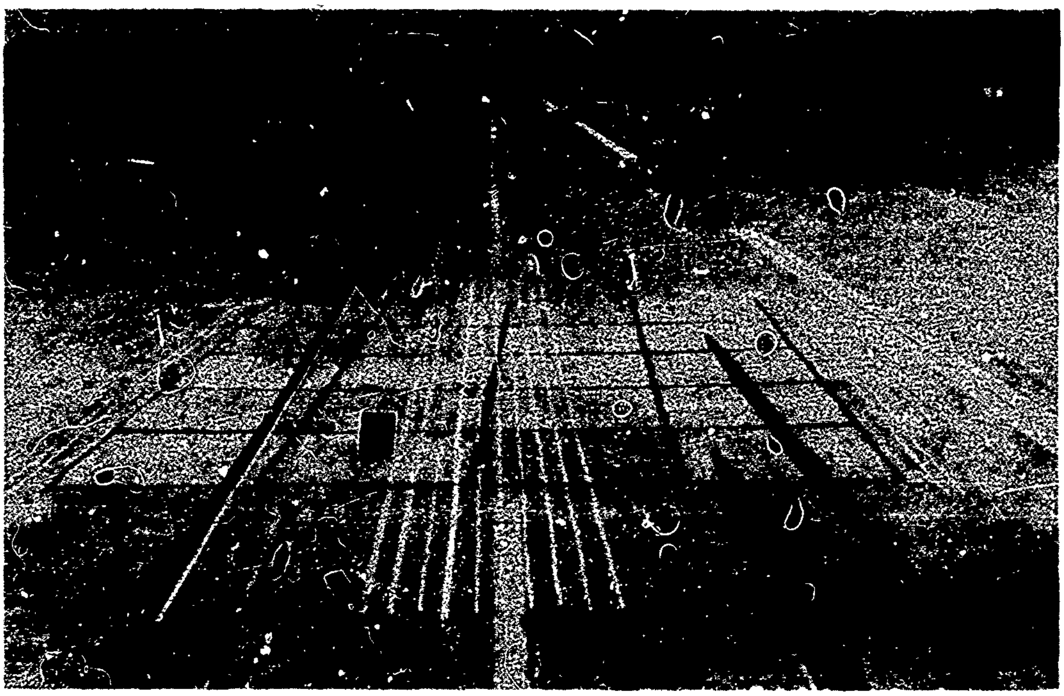


Photo 29. F-15 traffic lane after 2 coverages, precast slab repair

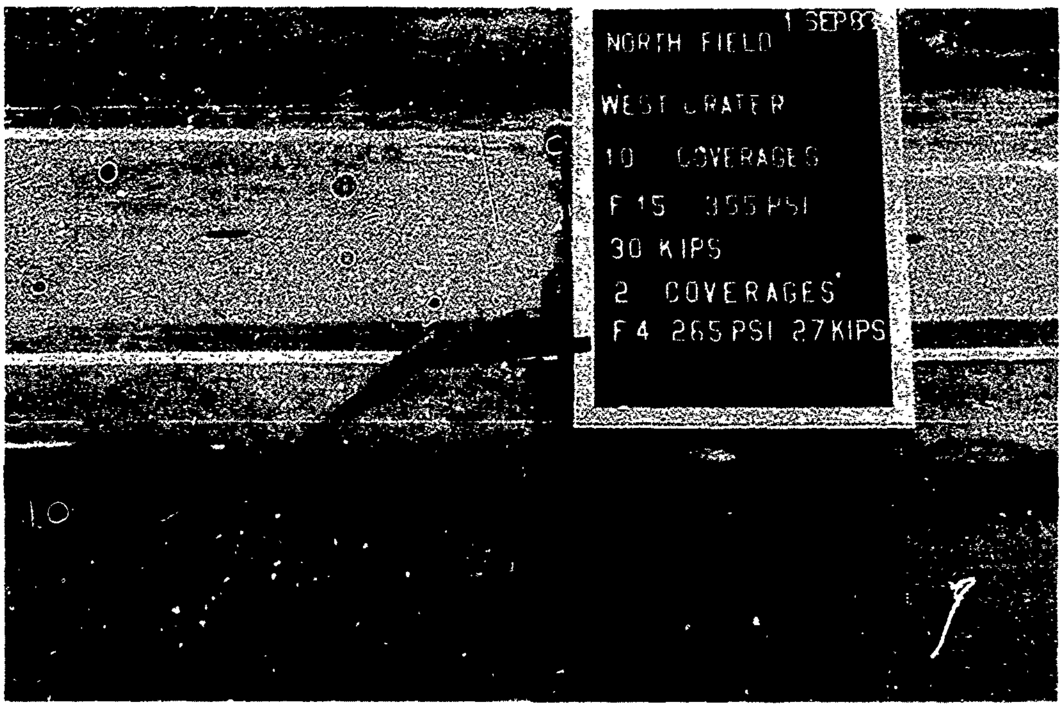


Photo 30. Spalling and sag measurement after 10 coverages of F-15, precast slab repair

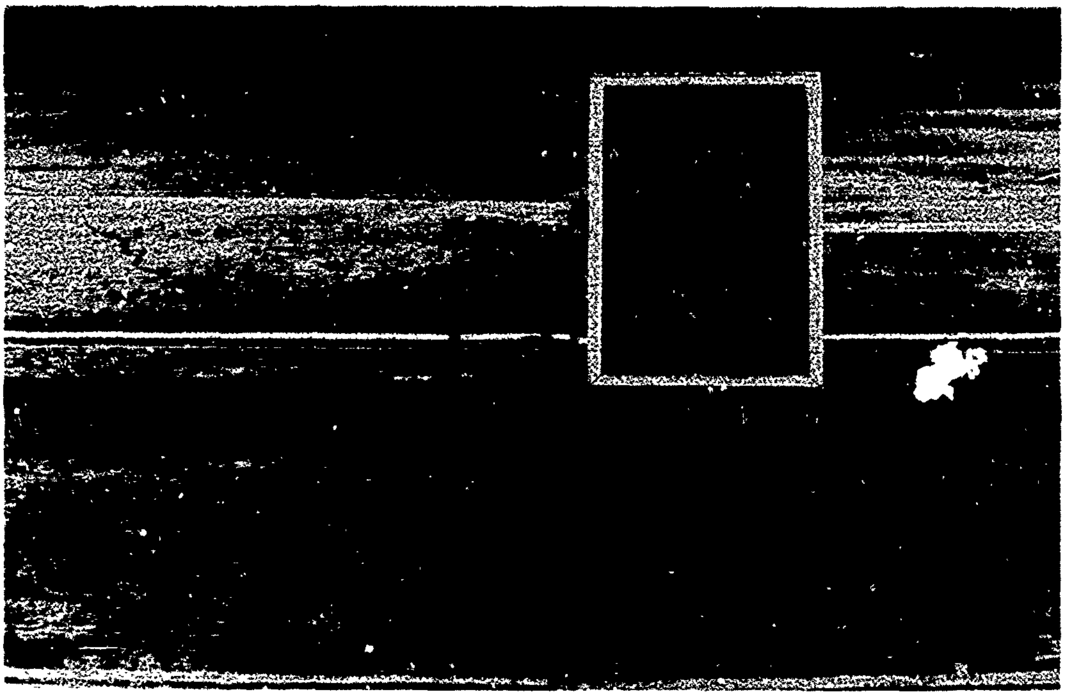


Photo 31. Sag measurement and spalling after 14 coverages of F-15, precast slab repair

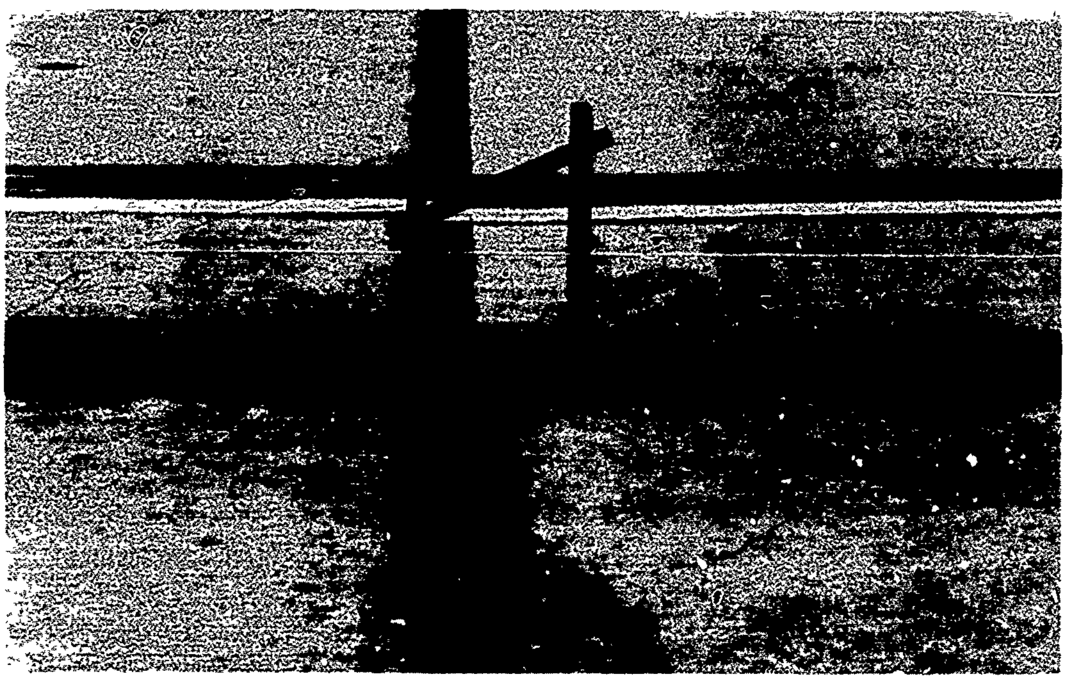


Photo 32. Sag measurement and spalling after 16 coverages of F-15, precast slab repair

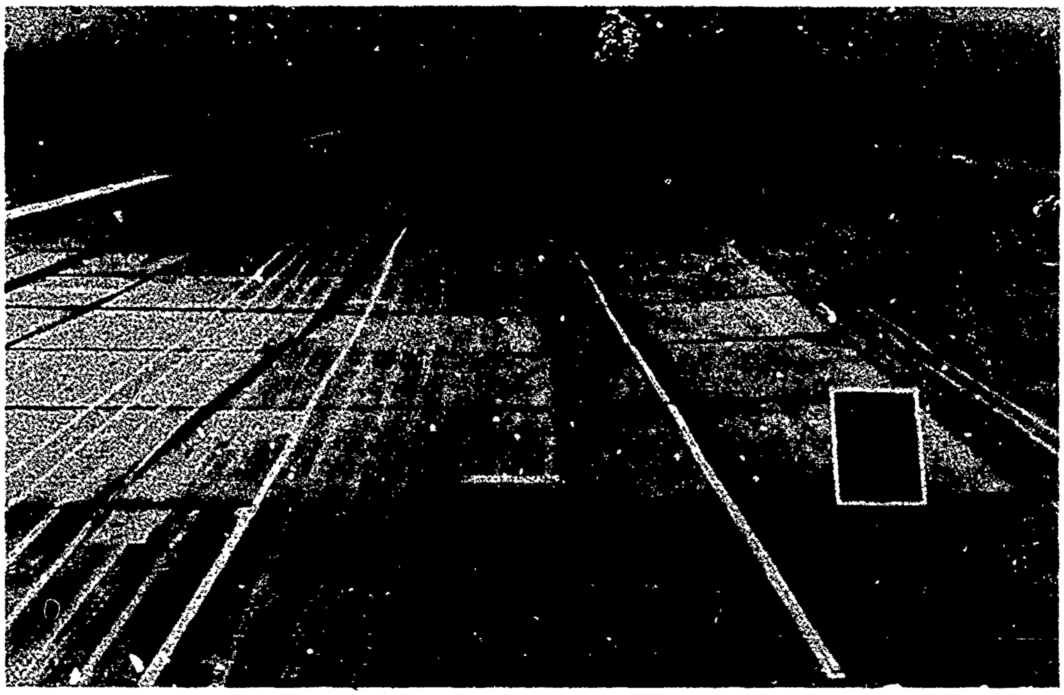


Photo 33. General view of F-15 traffic lane after 16 coverages, precast slab repair

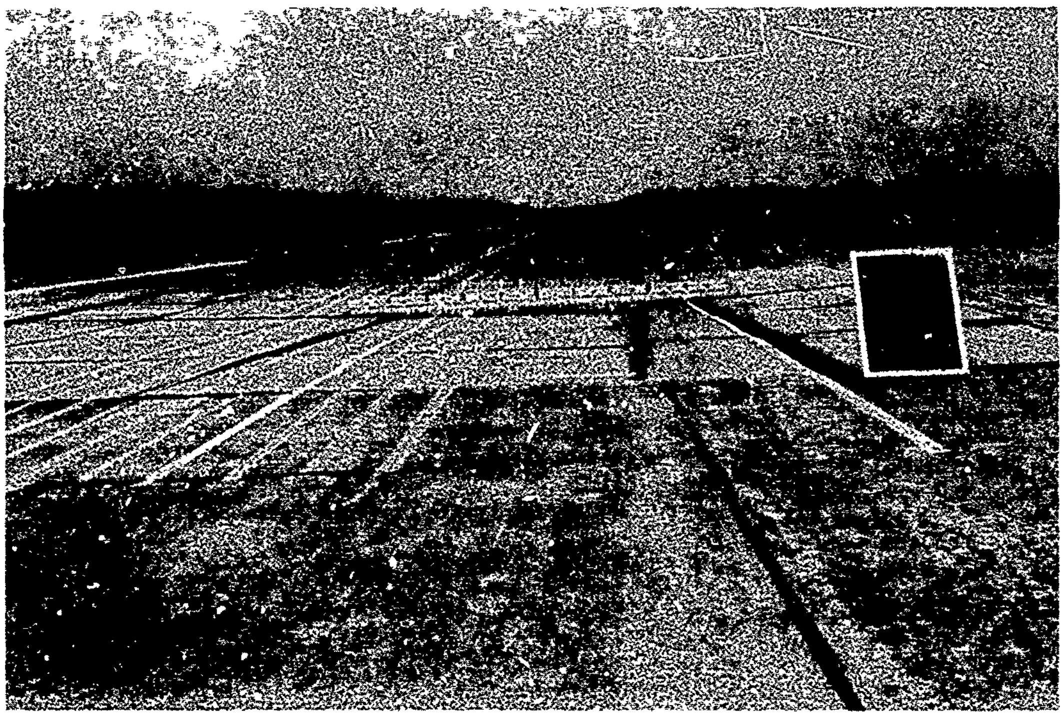


Photo 34. F-15 traffic lane with 10-ft straightedge after 16 coverages, precast slab repair

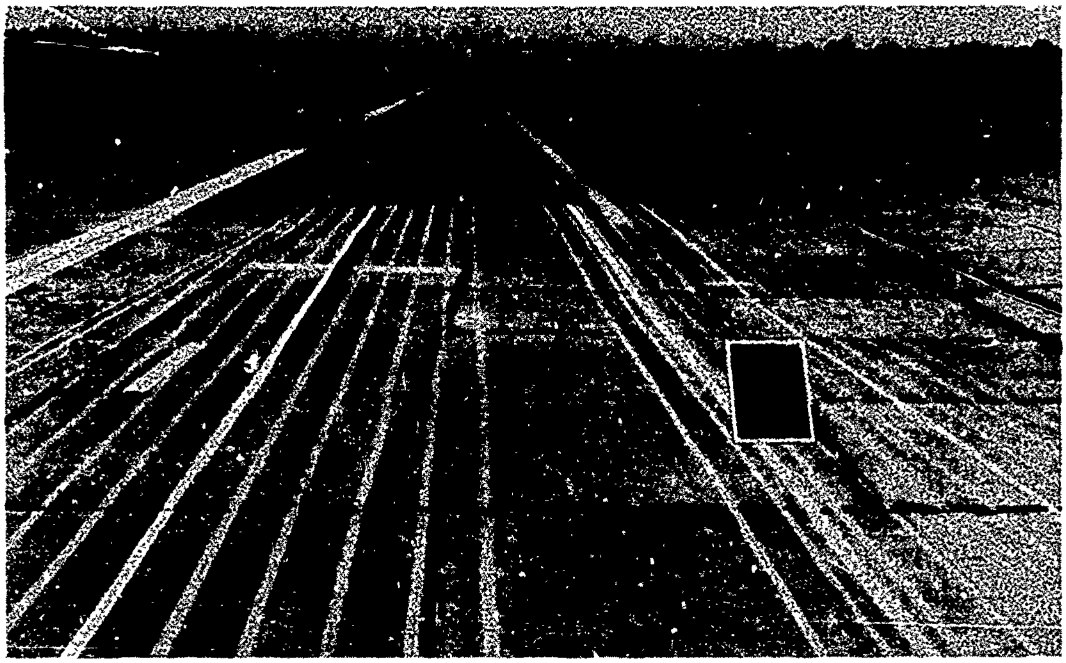


Photo 35. General view of F-4 traffic lane after proof testing and after aircraft traffic but before load cart traffic

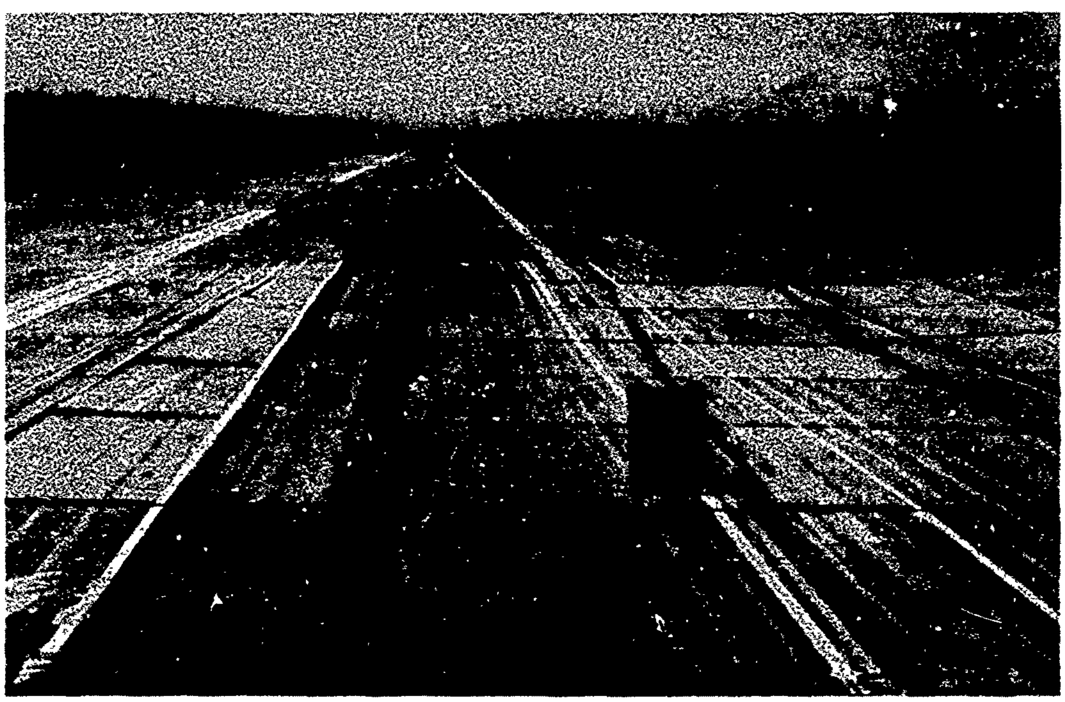


Photo 36. F-4 traffic lane after 10 coverages, precast slab repair

Photo 37. F-4 traffic lane after 20 coverages, precast slab repair

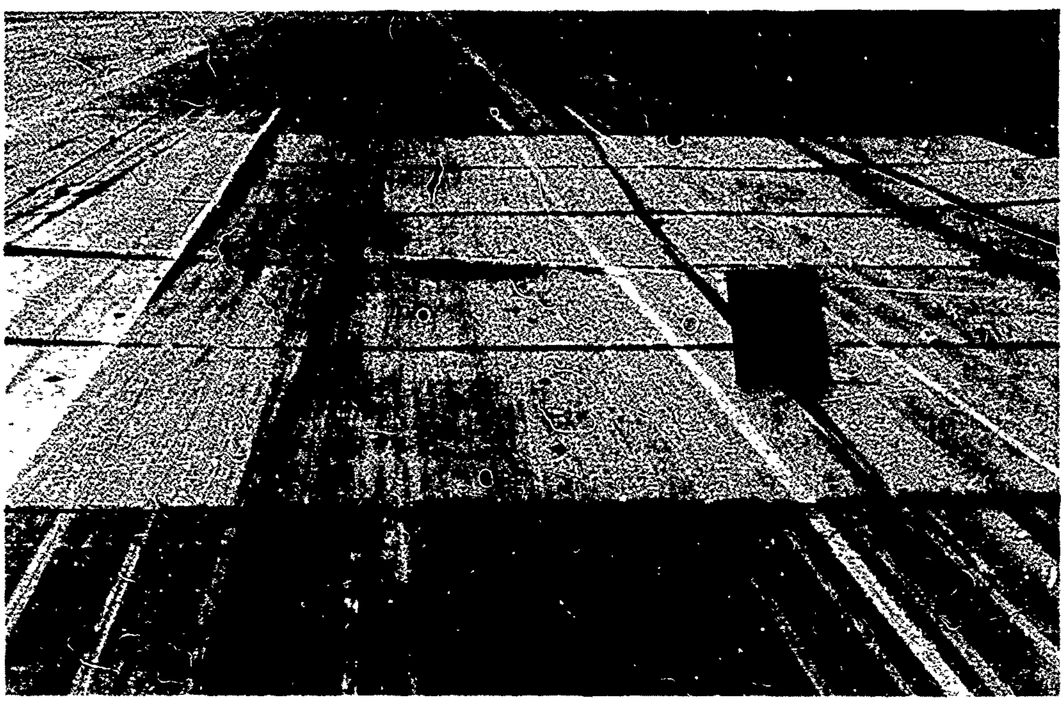


Photo 38. F-4 traffic lane after 30 coverages, precast slab repair

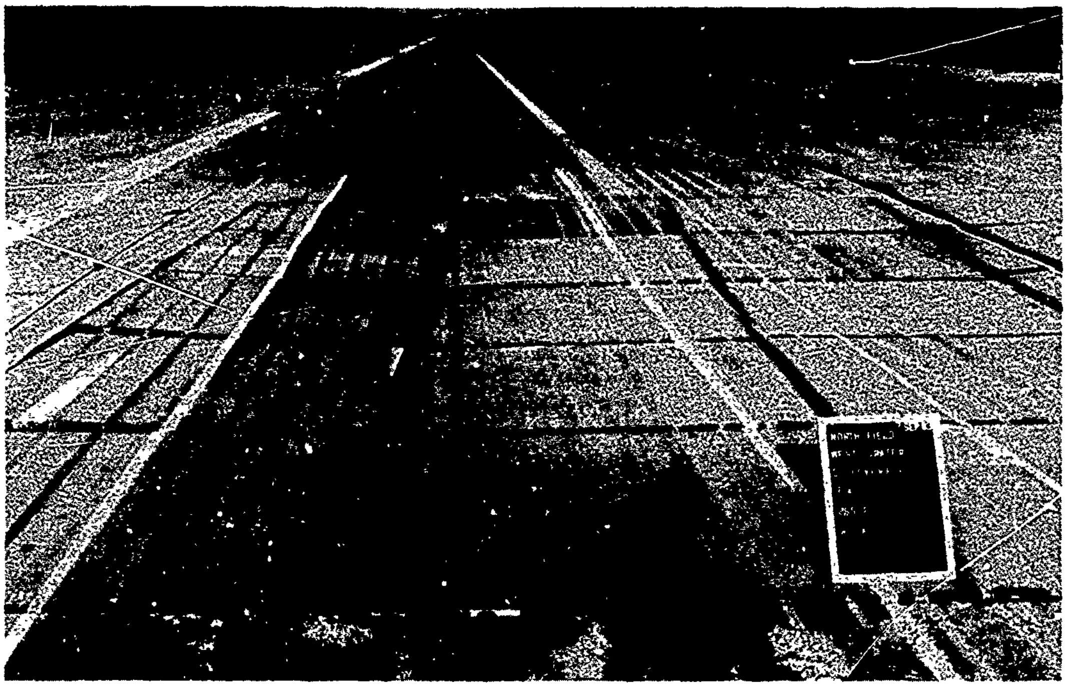


Photo 39. General view of F-4 traffic lane after 50 coverages, precast slab repair

Photo 40. Precast crater repair with slabs removed after all traffic

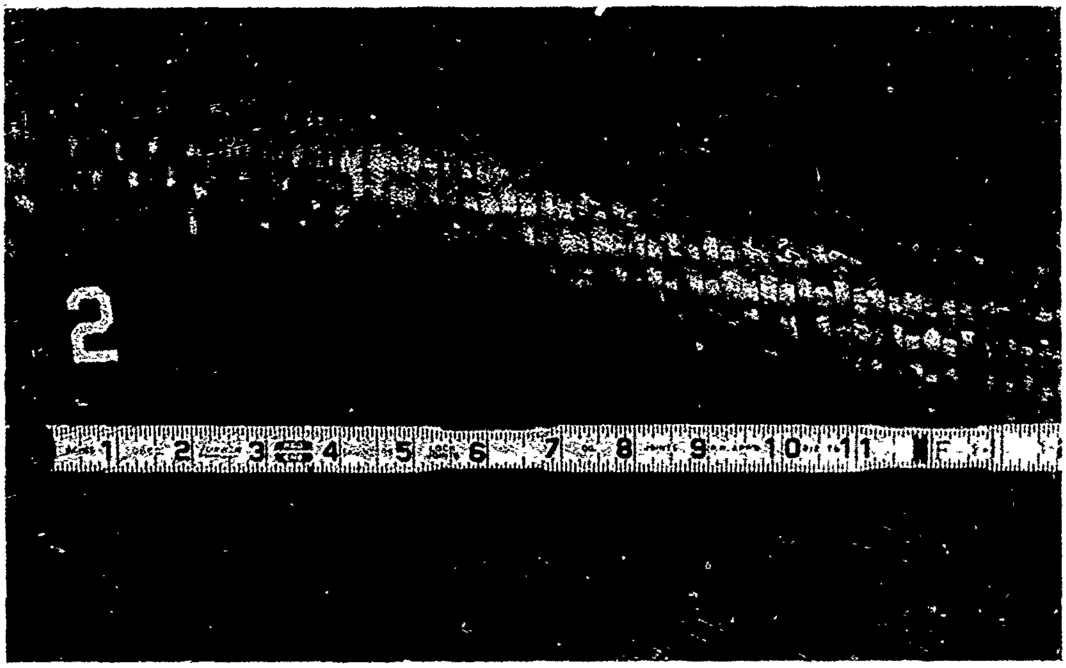


Photo 41. Tear in the top ply of the FOD
cover after proof loading

Photo 42. Area where the top layer of fiberglass was removed by the
aircraft in a takeoff attitude with afterburners on

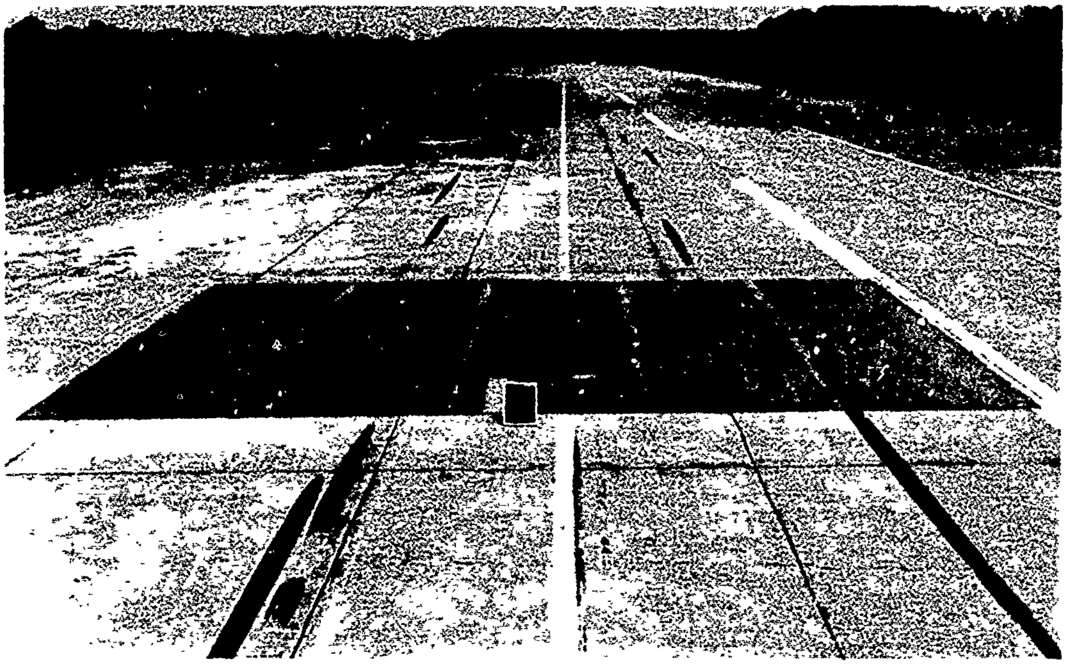


Photo 43. General view of FOD cover repair after F-4 aircraft traffic

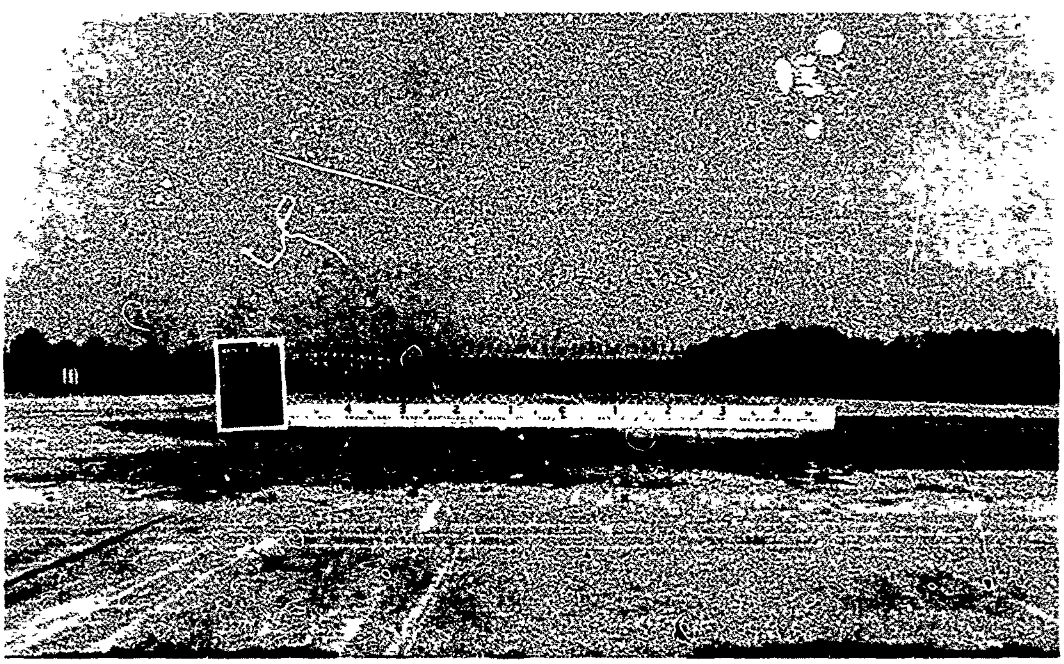


Photo 44. Rutting in the base course of the FOD cover repair

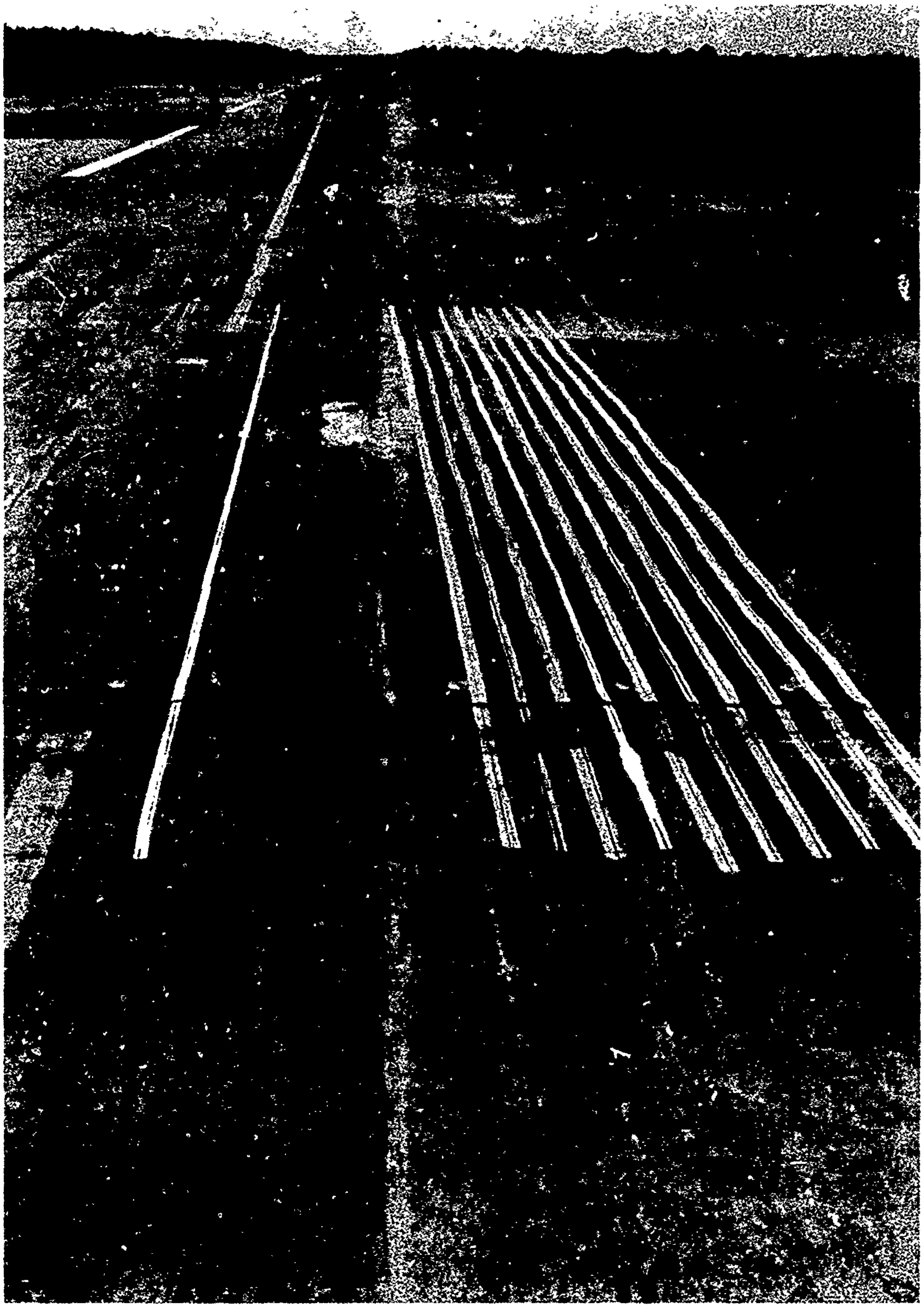


Photo 45. General view of the F-15 traffic lane after 2 coverages, FOD cover repair

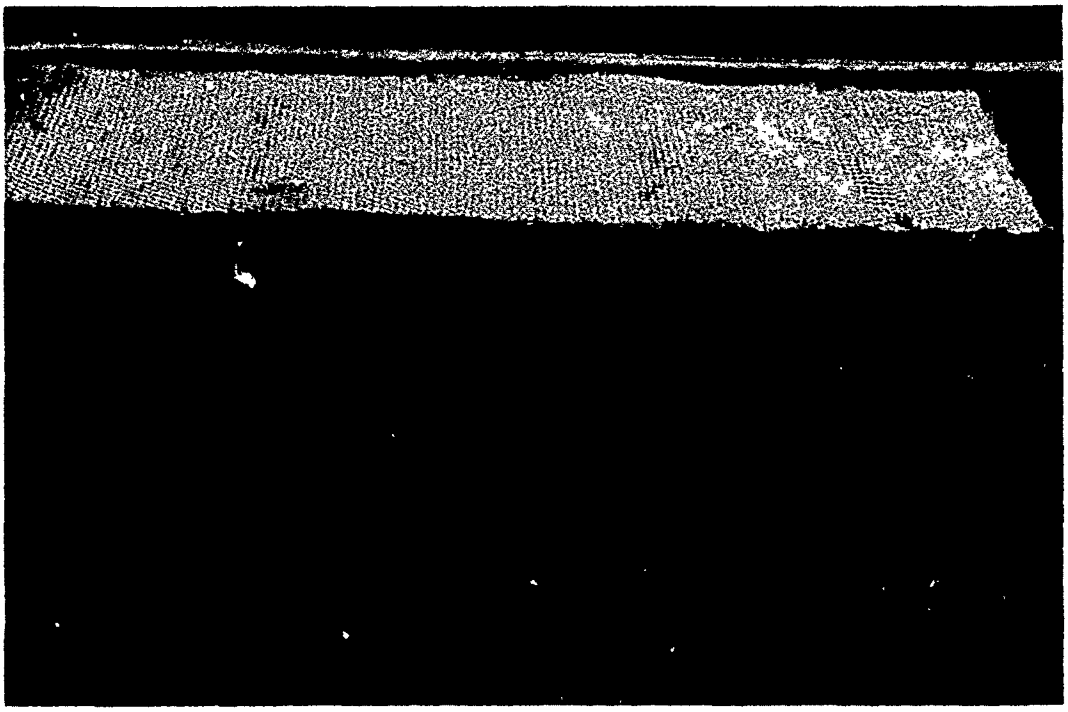


Photo 46. Tear along the hinge in the FOD cover after 4 coverages of F-15 and the fiberglass material to be used in the patch

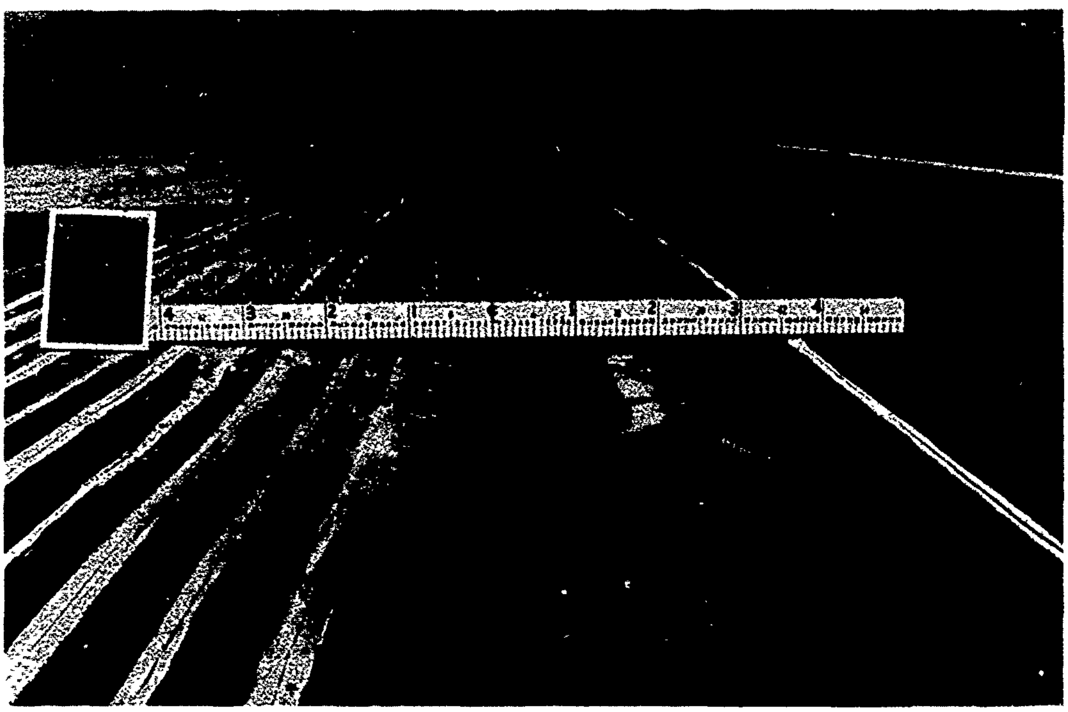


Photo 47. F-15 traffic lane after 6 coverages, FOD cover repair

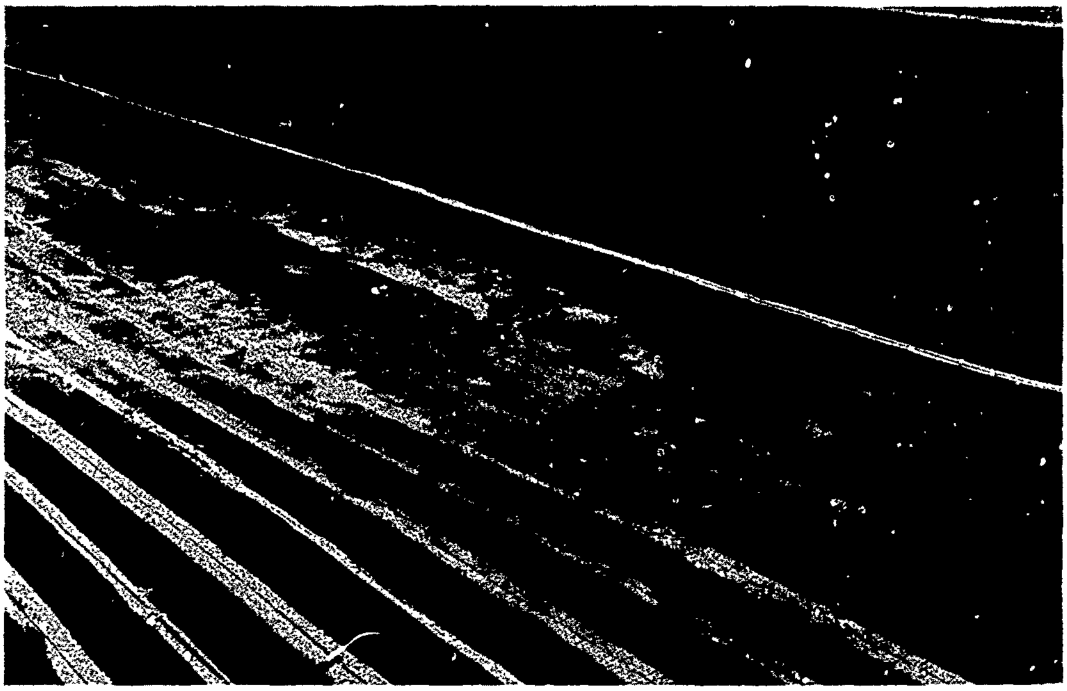


Photo 48. Tear in FOD cover hinge after 6 coverages of F-15 traffic

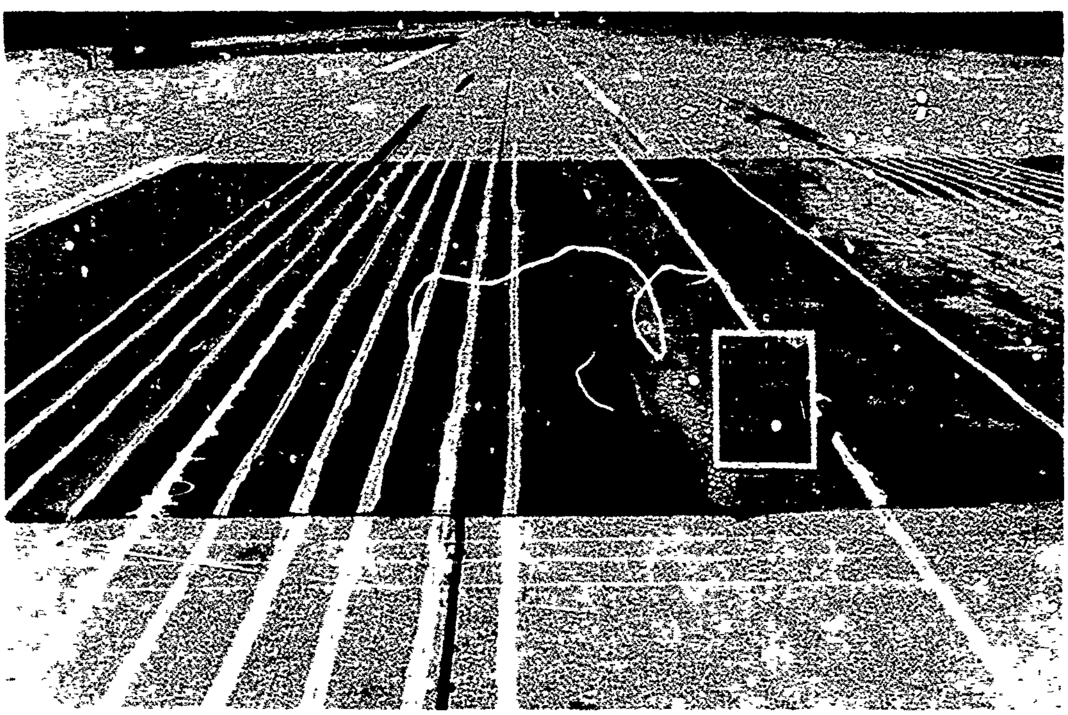


Photo 49. F-4 traffic lane before traffic was resumed, FOD cover repair

Photo 50. Tears along the hinge after 6 coverages of F-4 traffic, FOD cover repair

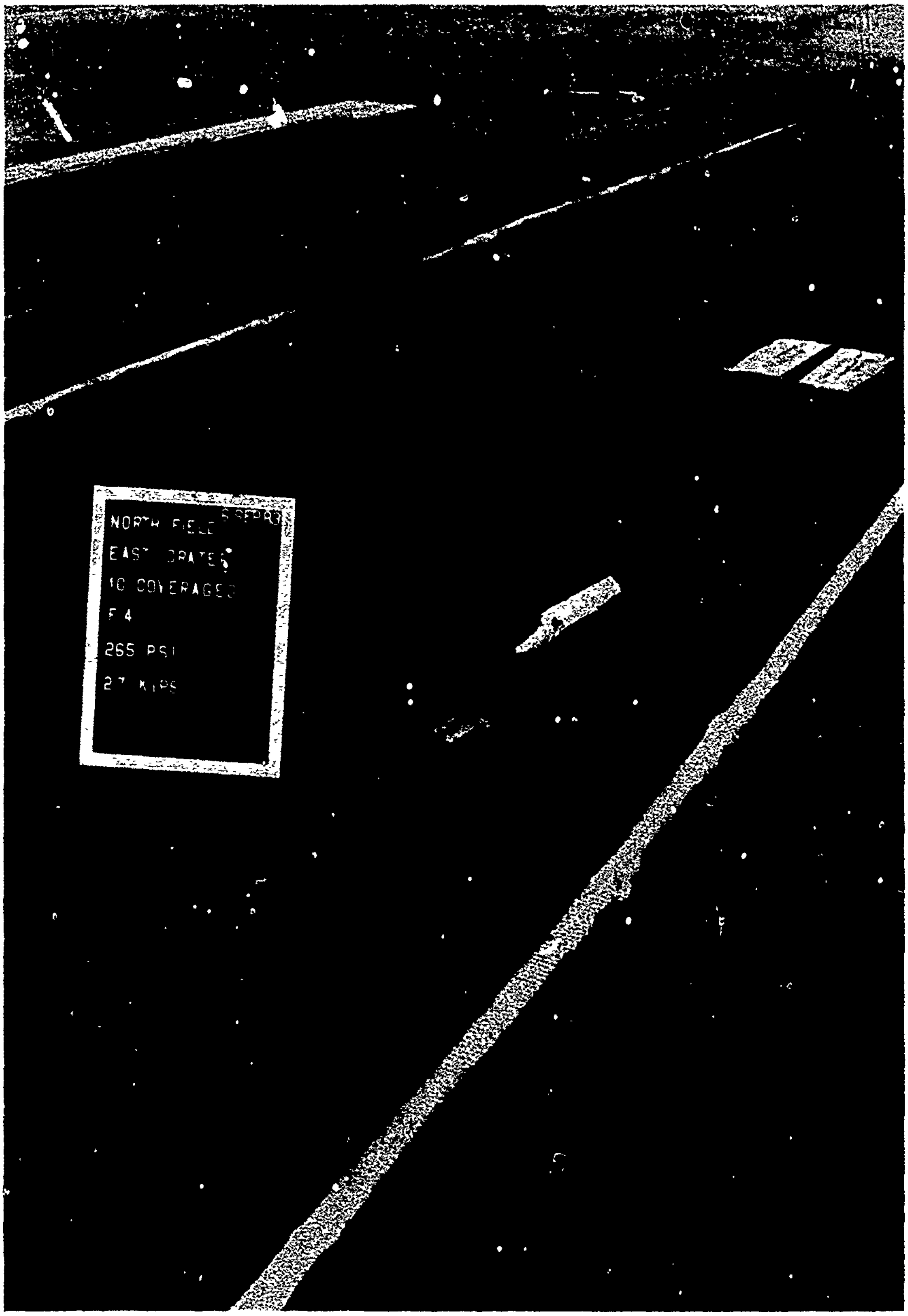


Photo 51. Surface condition along the hinge in the F-4 traffic lane after 10 coverages, FOD cover repair

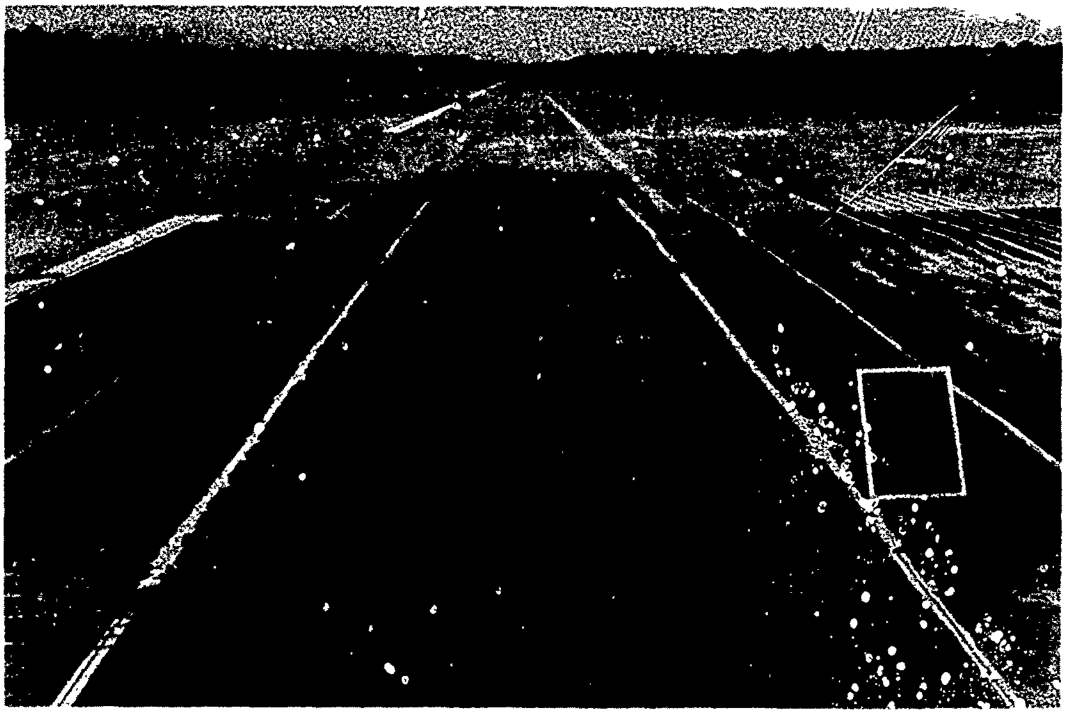


Photo 52. General view of traffic lane after 20 coverages of F-4 traffic, FOD cover repair

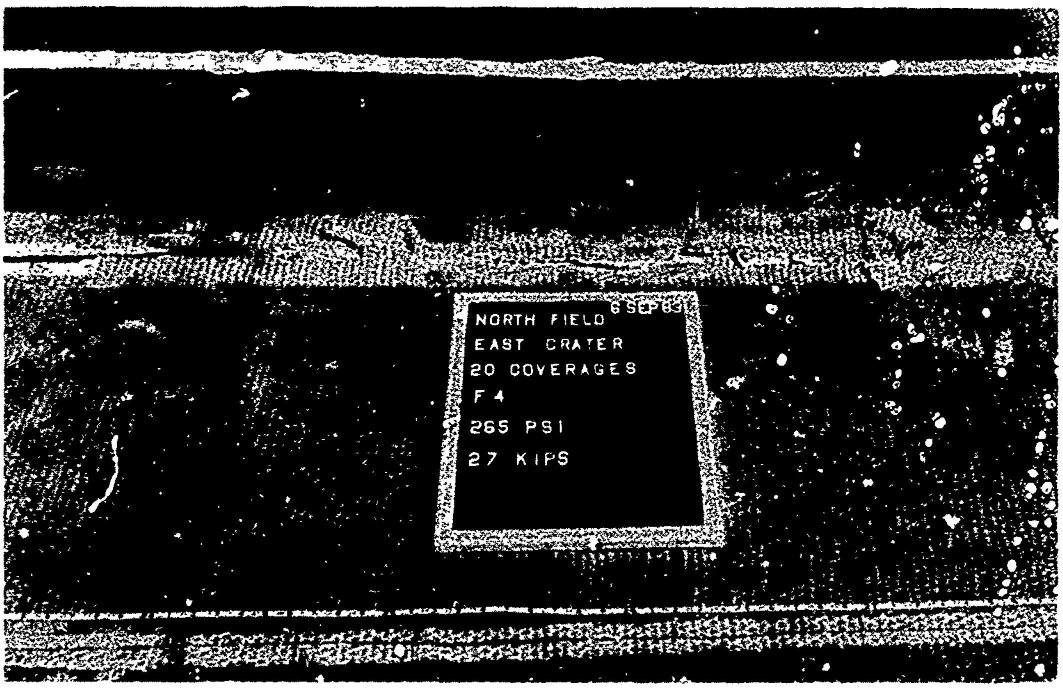


Photo 53. Close-up of spalling on torn hinge in the FOD cover repair after 20 coverages of F-4 traffic

Photo 54. Base course with FOD cover removed; water standing in F-15 traffic lane on the left and water standing in the F-4 traffic lane on the right